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Decentralized Energy Trading for Grids Using Blockchain for Sustainable Smart Cities

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Abstract

Blockchain technology can be used to create a decentralized energy trading system for grids that rely on renewable energy sources. This system would allow individuals and organizations that generate renewable energy, such as solar or wind power, to sell excess energy to others on the grid through a peer-to-peer network. Blockchain has smart contracts that facilitate the transactions and ensure that the energy is exchanged securely and transparently. This type of system can increase the efficiency and flexibility of the grid, and help to improve the acquisition of sustainable energy resources. The system allows organizations and smart homes that generate sustainable energy to trade excess energy to others on the grid through a peer-to-peer network, facilitated by smart contracts. The use of blockchain in this manner can increase the efficiency and flexibility of grids and promote the adoption of renewable energy sources. Blockchain technology possesses the potential to transform the energy trading system by creating a decentralized, secure, and transparent P2P energy trading facility for grids that rely on renewable energy sources. This facility allows the trading of energy that is produced in excess by any entity through smart contracts. By using blockchain technology, the energy trading process is more efficient, secure, and transparent, and it can facilitate the adoption of sustainable energy sources. The implementation of such a system, however, requires collaboration between various stakeholders and compliance with existing regulations and standards of the energy sector. Despite the challenges, the potential benefits of a blockchain-based smart decentralized energy trading system make it a promising solution for the future of the energy sector.

Keywords: *Blockchain, Decentralized Energy Trading, Distributed ledger, Sustainable Smart Cities, P2P networks*

1. Introduction

The increasing use of sustainable energy sources has paved the way for the progress of smart grid systems that can efficiently and flexibly manage the integration of these energy sources into the power grid. However, current centralized trading systems for renewable energy have limitations in terms of transparency, security, and efficiency. Blockchain Technology, with its decentralized and secure nature, has the potential to overcome these limitations and enable a more efficient and fair energy trading system for renewable energy [14]. This article will discuss the use of a decentralized energy trading

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platform for grids using blockchain for sustainable energy resources and how it can improve the transparency, security, and efficiency of the energy trading process. The transfer of renewable energy sources into the power grid has been an arduous task due to the decentralized and variable nature of these sources. The development of apt grid systems has helped to mitigate these challenges, but current centralized trading systems for renewable energy still have limitations in terms of transparency, security, and efficiency. Blockchain technology offers a way around these limitations by furnishing a segregated and safe platform for energy trading. The use of smart contracts, a salient feature of blockchain, can enable a more coherent, transparent, and fair energy trading system for renewable energy. This introduction will discuss the power of blockchain technology to transform the trading system for grids that rely on renewable energy sources, and how it can better the efficiency, safety, and transparency of the energy trading process [13].

1.1 Background Work

The tremendous expansion of renewable energy sources over the past ten years, including novel power plants for electrical energy, generators, and electric vehicles, and the emergence of a latest variety of grid entities referred to as prosumers, has led to the comprehension of the smart grid topic in the field of power engineering. A completely new means to record data and conduct transactions has been invented almost simultaneously with the groundbreaking advent of blockchain technology. It guarantees immediate regulatory authority control of transactions and provides a clear view of the system's functioning to all stakeholders. The blockchain, smart contracts, consensus algorithm, and decentralized market are the foundations of decentralized energy trading platforms for grids using blockchain for sustainable energy resources [7]. A blockchain is a type of data structure that uses a particular distributed ledger implementation. It consists of contiguous blocks with sets of negotiations that are coupled together cryptographically. These blocks are then often broadcast to all users linked to the blockchain's P2P network. Crypto contracts are automatic computer programs that accordingly perform operations like writing to or reading from the segregated ledger when specific criteria are encountered. The purpose of the consensus method is to prevent malicious parties from altering the data on the ledger by ensuring that it is the same for every user of the blockchain network.

1.2 Motivation

The inception of every new invention idea happens as a part of creating a new solution, blockchain is one such technology that has been a major field of research and implementation. A brief history of blockchain tells us that it was developed as a result of a highly uncertain economy, blockchain boasts its implementation in fields where there is no or minimal trust. The success of the implementation however cannot be alone credited with blockchain as other protocols also have played a major role in making this technology a success. The technology has a decentralized nature of computation even in busy P2P networks and because of its publicly distributed ledger, which provides transparency over the entire blockchain, this technology is a go to solution to be implemented. Given the advantages of blockchain and the robustness of the same, there lies a potential solution to solve the problem of energy trading for sustainable energy resources [10,15]. The existence of centralized entity for the trade of the excess energy produced by any entity has resulted in the loss of energy, hence this work finds its motivation in the robustness of the blockchain and a solution for the above discussed problem.

2. Literature Review

The authors of paper [1] are of the opinion that as a result of the widely distributed energy generation and the quickly increasing energy consumption, new demand-side management techniques are being created. A demand response mechanism built on blockchain is suggested to control energy generation and demand. The electricity consumers heed this

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signal in order to receive rewards and stay out of trouble. However, load restriction is used to balance their load, which is ineffective for their comfort. A potential answer is peer-to-peer energy trading [8]. Electric current prosumers make use of RESs to produce energy close to where they live in a P2P energy market based out of blockchain. After their energy needs are met, extra energy is sold in the market with consumers who have a shortfall of energy. A composite P2P power trading merchandise mechanism has been proposed, implementing Peer-to-Peer and seller to grid (P2G) power negotiations [11,12]. Decentralized double closed book auction is the basis of the market. Here, extra power can be put up for sale and shortfall power could be purchased from the utility grid or nearby sellers. According to the study's findings, only consumers who have registered can trade. One bid from a single customer is the maximum for a given window of time. At any one time, a prosumer may buy or sell energy. The cost of power must fall within the range of the utility grid's lowest price and maximum price on the local market. The local market's energy trading price will always be less than the utility's pricing. The authors of paper [2] are of the opinion that a few local, vertically integrated monopolies have historically served as the foundation for the production, trade, and delivery of electrical energy, which has been a process that is centralized. Today, the proportion of energy produced by former customers—now referred to as "prosumers"—using renewable energy sources is steadily rising, creating an environment that is decentralized in which the distinction between producing entities and consuming entities is becoming increasingly hazy. A system with an ordinary seller serving as the supplier of last resort and the medium of exchange was presented. It is built on a shared supraordinal grid, aggregator nodes, and intelligent agent trading. The authors demonstrated how blockchain and distributed ledger technology are perfect fits for this issue. Blockchain technology accommodates distributed ledger technologies because of their extremely high security and dependability, and can be carefully specified. The case study in [3] that explores the use of a permissioned blockchain system to facilitate energy trading among residential communities. The study aims to reduce peak demand for electricity by incentivizing residents to shift their energy consumption to off-peak hours. The suggested system makes use of an acknowledged blockchain, which allows for controlled access to the network and secure the certainty and confidentiality of the participants. Crypto contracts are utilized to automate the power trading process and enable real-time monitoring and tracking of energy transactions. The study used a real-world residential community in Taiwan as a testbed for the proposed system. The outputs of the case study emphasize that the proposed power trading system based on blockchain was able to effectively decrease crest requirement and improve the overall efficiency of energy consumption in the community. The study also highlighted the potential for the proposed system to be scaled and replicated in other residential communities, which could lead to significant reductions in peak demand and energy costs for both residents and utilities. Overall, the study demonstrates the potential of using blockchain technology to facilitate energy trading among residential communities and reduce peak demand for electricity. The study proved that the proposed system could be effective in reducing peak demand and promoting energy efficiency. This can be replicated in other residential communities and can lead to significant reductions in peak demand and energy costs for both residents and utilities. Paper [4] explores the potential utilization of blockchain technology for grid governance. The authors discuss the benefits of employing blockchain for grid governance, such as increased security, transparency, and decentralization. They also identify several future scenarios for the integration of blockchain in smart grid management, including distributed energy resource management, demand response management, and fraud detection. The authors also

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identify several challenges that need to be addressed in order to successfully implement blockchain in smart grid management. These include regulatory challenges, scalability issues, and the need for standardization. They also suggest that further research is needed to fully understand the potential of this technology for grid governance and to identify potential fix to the identified challenges. In summary, the paper discusses the potential benefits of blockchain technology for smart grid management, along with future scenarios and scope that need to be addressed in order to successfully implement it. The paper also emphasizes the need for further research in this field. [5] proposes one of the most promising strategies in crypto Grid is Transactive Energy Management (TEM) The present P2P systems have a number of problems, which includes network bandwidth, single points of failure, scalability, and challenges with safety and trust. To address the above problems, this study suggests a blockchain-based Decentralized Transparent Peer-2-peerP Energy Trading (DT-P2PET) strategy The DT-P2PET system conducts peer-to-peer energy trading using Smart Contracts (SCs) built on Ethereum blockchain and the Interplanetary File System (IPFS). In addition, this study addresses a recommender method to improve the proportion of sellers and consumers. In the suggested DT-P2PET scheme, the Ethereum SCs are created, implemented and deployed to carry out peer-to-peer in real time. Based on a number of factors, including its ability to generate profits (for both producers and consumers), bandwidth of network, data storage costs and transfer rates compared to current methods, the DT-P2PET scheme is assessed. The suggested DT-P2PET scheme uses a dynamic pricing mechanism in order to increase gain for both consumers and sellers while lowering the burden of generation and management of energy on the grid. The authors of paper [6] are of the opinion that the improvement of decentralized energy management systems has accelerated today as a result of the daily expansion of communications infrastructure and renewable energy technology. For managing local generation units, a new operating model is emerging: The local energy market. explains the general design and components required to construct a transactive management platform-based local energy market based on blockchain technology. Following that, the principles of technologies that are based on blockchain and the necessary descriptions for various developmental levels are detailed developed on the few pertinent material that is currently available. P2P, a new technology, has given users the opportunity to investigate novel applications and ideas to support creative business solutions. Utilizing these systems, consumers may use local, often clean electricity generation and reduce dependence on the centralized grid while prosumers can receive larger benefits for their electricity generation.

3. Existing System

The diagram in Figure 1 represents the existing system of distribution and storage of electric power produced through solar energy. The existing system is a centralized system where a central entity controls the production and storage of sustainable energy for commercial purposes [9], the solar energy harnessed through solar panels in homes is strictly for domestic use only and any commercial use of the same is punishable, most of the energy produced is wasted as they are not properly stored and the stored energy from a central entity does not allow any commerce on the same. The central entities install solar panels which include solar cells that capture the solar energy; the captured solar energy is stored in batteries which further get into power generators before ultimately ending up at the consumer.

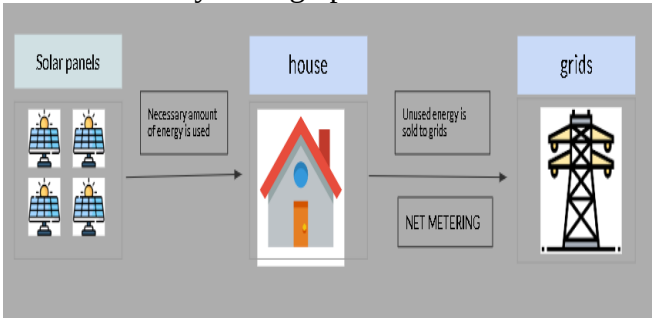

Figure 1 Figure Depicting Existing System

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3.1 There Are A Few Flaws in The Existing System

- **Centralized System:** because of a centralized system, there will always be a person or an entity controlling the entire system.
- **Lack Of Transparency:** the operation and distribution of energy is done by government entities and hence no details will be made public about the system, its administration, working
- **Safety Standards:** The existing system's security is fragile and is easily breakable at any point which will then be a single point of failure. (For example, Ukraine power grid attack)
- **Data Protection:** the data stored may not be safe and under the hazard of being compromised any time, which causes major operational disturbances.

4. Problem Statement

As a result of the rapid rise of demand in energy and generation of distributed energy, new management strategies are being developed. These techniques establish financial sanctions and rewards that motivate consumers to participate in the suggested demand response programs. A demand response program based on blockchain should be proposed to control energy demand and generation. The electricity consumers heed this signal in order to receive rewards and stay out of trouble. However, load restriction is used to balance their load, which is ineffective for their comfort. To get around this restriction, P2P seems to be a potential solution.

5. Proposed Solution

Every issue now in existence needs a long-lasting, viable solution. For the issue raised in the previous study, a decentralized approach based on blockchain for sustainable smart cities is suggested. The energy trading marketplaces on blockchain have a 2-layered design as shown in Figure 2.

- The blockchain is implemented on the virtual layer. Each user on the market has the same version of the distributed ledger and is a node in the blockchain. Through a smart contract, an energy seller submits a bid so that energy in the energy market can be sold. The smart contract and the APIs which are essential to interact with them are present in this layer.
- The application layer is the second tier in this design. Smart contracts are interacted by user and user submits the information, and also user maintains record of crucial information using a UI and decentralized applications (DApps), which are both components of the system. To communicate with the system, a network participant uses the application layer.

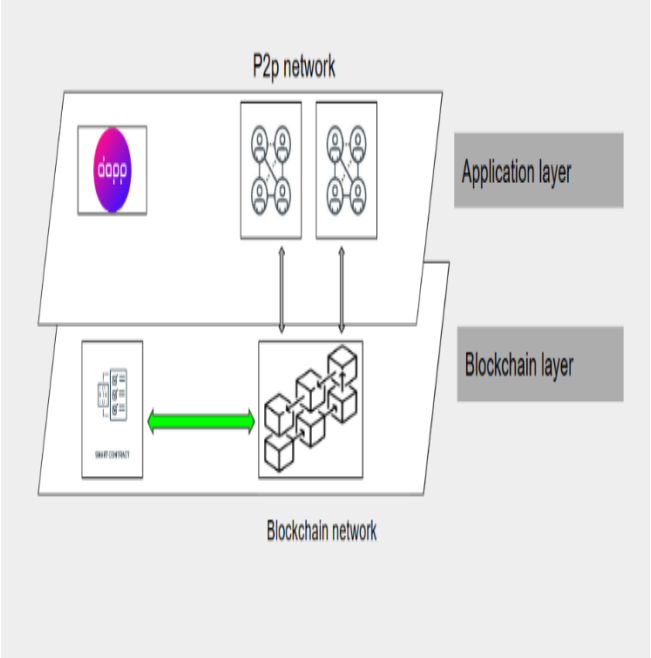

Figure 2 Proposed System

6. Implementation

The project implementation was carried out in 2 layers as proposed in the solution using trending Tech Stack, which include ReactJS for frontend, NodeJS for backend, Solidity to develop smart contracts, Truffle framework to test and deploy smart contracts and Ganache to test and manage private blockchain network.

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6.1 Smart-Contracts

smart-contracts are the heart and soul of any blockchain application, smart contracts are set of rules and regulations that are verified before conducting a transaction, the project was based on 2 smart contracts, buy and sell, the former handles the prosumer buy request by validating the smart contracts and interaction with the MetaMask wallet, if the interaction is successful, the transaction is carried out further, the latter handles prosumer selling the energy, the prosumer through the website will enter the amount of energy available and the price is automatically calculated, and again a smart contract is initiated, only successful interaction would lead to a successful selling of energy.

6.2 Dynamic Pricing Algorithm

a dynamic pricing algorithm that will handle the electricity prices based on the date, time, time of the year, season and other few factors, based on these factors current price is calculated against a fixed value of the electricity, these dynamic prices give user a chance to earn incentives based on demand while encouraging buyers to go greener Further the solution was implemented as a prototype website that need manual communication from seller about the availability and need of energy, integration with smart meters and smart grids would make the process fully automated

7. Results and Discussion

7.1 Buy Section

This part allows prosumer to buy energy from available energy, the user can buy any amount of energy from the listed entities based on their choice, once the required quantity is entered a transaction is initiated via smart contracts, smart contracts validate the user and opens wallet for payment, the user can connect his MetaMask wallet for transaction, the amount is deducted from the user and is sent to the contract which in turn will send it to seller. The following picture of MetaMask wallet shown in Figure 3, will handle buying of energy with the help of blockchain.

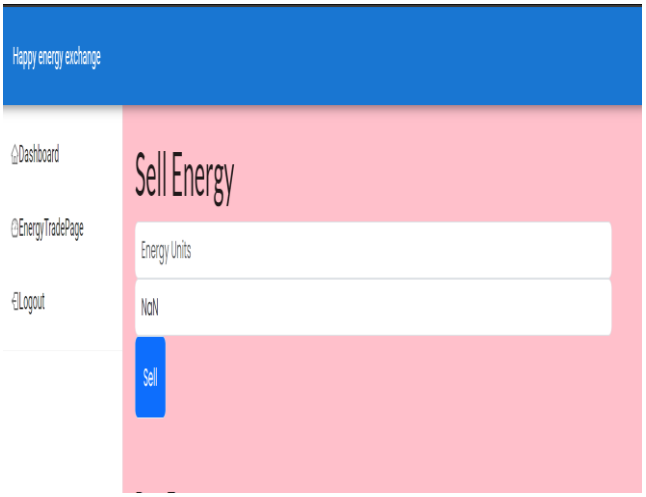

Figure 3 Buy energy section

7.2 Sell Section

This part allows prosumer to sell energy on the platform, the prosumer need to enter the available energy details and the price is calculated based on the algorithm and wallet opens up after smart contract initiation, no amount is deducted, but gas fee is collected to facilitate the transaction and handle the blockchain network. The following picture of MetaMask wallet shown in Figure 4, will handle selling of energy with the help of blockchain.

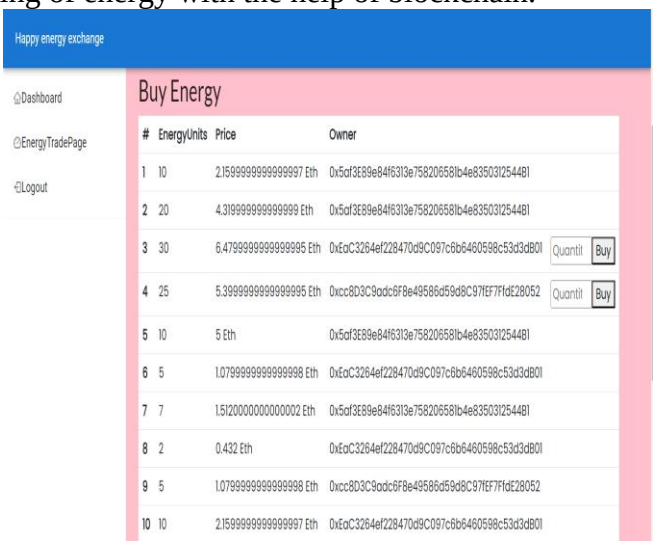

Figure 4 Sell energy section

7.3 Seller Interaction

The smart contract interacts with the wallet to facilitate transaction, when the seller hits the sell button, wallet open up and contract interaction

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happens, a certain gas fee is collected from the seller to facilitate transaction and handle the blockchain network. The seller interaction is shown in Figure 5 below. [15]

7.4 Buyer Interaction

Prosumer who wants to buy, inputs required number of units, the price is calculated and wallet opens up, the smart contract interacts with the wallet to deduct the required amount and gas fee from the buyer, after successful transaction the amount is sent to the smart contract which will in turn send it to seller. The buyer interaction is shown in Figure 6 below.

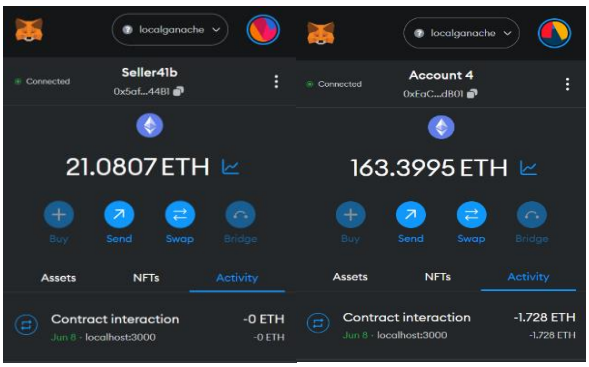

Figure 5&6 Sellers Interaction and Buyer Interaction

Conclusion

The decentralized energy trading platform allows users to trade their green energy. This project was built as a prototype to facilitate the trade of energy to make the cities more sustainable and green, leveraging latest tech stack and languages, project was totally built on JavaScript language with the landing page from bootstrap, smart contracts were developed using solidity and deployed using truffle framework, the application has many parts out of which dashboard and energy-trade sections are of prime importance, dashboard allows users to interact with the website and gain insights, while the energy trade section allows prosumers to buy and sell energy, the blockchain is tested on ganache, which is an open source application to test the network and deploy smart contracts while facilitating the payments through MetaMask wallet, in conclusion the website allows and encourages users to trade the solar energy for greener and sustainable tomorrow. The project boasts itself of a dynamic pricing algorithm that dynamically changes the current price based on the predefined conditions, which not only creates a competitive market space, but also acts as a source of incentive for the users.

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