Blockchain-Based Decentralised Energy Trading Using Micro-Grids

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ABSTRACT: Electricity plays such a significant role in our modern lives that one cannot imagine a world without it. As the electricity consumption increases, and due to the high prices, it becomes a big issue to maintain carbon neutrality in the world. As a result, we use microgrid technology with blockchain and the integration of renewables, and energy storage. When a centralized power grid malfunctions or goes down due to natural calamities, then the backup for the electricity will be microgrids as they work in a decentralized manner. Each user can sell and buy energy thereby building a strong energy trading network. We have used blockchain to implement a Peer-to-Peer (P2P) energy trading system. Blockchain provides the architecture for the microgrid. We can enhance security and produce transparency and a completely auditable ledger in the network by using smart contracts for energy transactions. Due to the use of a decentralized network, the identity of users is secure because each user has their own digital hashed signature. On implementation of the proposed system, we can bring down the cost and trade energy between prosumers and consumers as and when required, without any intermediary intervention.

Keywords: Blockchain, DApp, Microgrid, Ethereum, IPFS, Peer to Peer, Ledger, Cryptocurrency, Crypto Wallet, Decentralized Network, Prosumer, Consumer, Smart Contracts, Energy Transactions, Public Key Cryptography

INTRODUCTION

1.1 Background

To understand the working of the Blockchain, we've divided it into four parts:

1. Structure of Block
2. Chaining or Linking of the Blocks
3. Digital signature
    a. Asymmetric Cryptography
4. Mining
    a. Proof-of-work
    b. Proof-of-Stake

1.1.1 Structure of Block

Block is a group of valid and verified transactions. Each block is immutable. Miners continuously process new transactions, and new blocks are going to be added to finish off the chain. Each block will have the hash of the previous block thus ensuring the integrity of the chain. The first block of the chain has a previous hash value of 0000 and is called a genesis block.

The contents of the blocks are:

- **Hash of the previous block: -** This contains the previous block's hash value. This means, that for every block N, we feed it the hash of block N-1.
- **Hash of Current block: -**This contains the hash of the header of the block which will act like the previous block's hash in the next block.
- **Timestamp: -** This marks the current time in seconds for each transaction done. The time is given in seconds since 1.1.1970.
- **Nonce: -** Nonce stands for "number only used once" which is a number added to a hashed block in a blockchain. It is the number that miners are solving for. It is used and adjusted by miners to make it valid for hashing the value of the block.
- **Merkle Root: -** All the transactions in a block are aggregated in a hash. The hash of the Merkle tree is the Merkle root.
- **Transaction ID List: -** It contains all the Transaction Details of the Users and is secured by a Merkle Tree.

The block header is 80 bytes:

1. Version number: 4 bytes
2. Previous block header hash: 32 bytes
3. Merkle root: 32 bytes
4. Timestamp: 4 bytes
5. Bits: 4 bytes
6. Nonce: 4 bytes

1.1.2 Chaining or Linking of the Blocks

Hashing is a method of cryptography that converts data of any length and gives out an output of a fixed length. A cryptographic hash function is considered secure, as it portrays certain properties like

- The result is always of the same length.
- Given a hash, in which we cannot determine the input data.
- Produce different outputs even if the input data gets changed by a digit or letter.

These properties lend a level of security to the blockchain.

Figure 1.1 illustrates how sections are chained together on a blockchain. Each block has a header and some transactions. Transactions happen to be hashed to get a resolved length hash output which can certainly be added to the mass header. Each subsequent valid mass must deliver the hash output from the prior block. The hash of the prior block header is employed to link many of the real blocks to the kinds just before it. A chain of obstructions is established by linking each block out to the previous block.

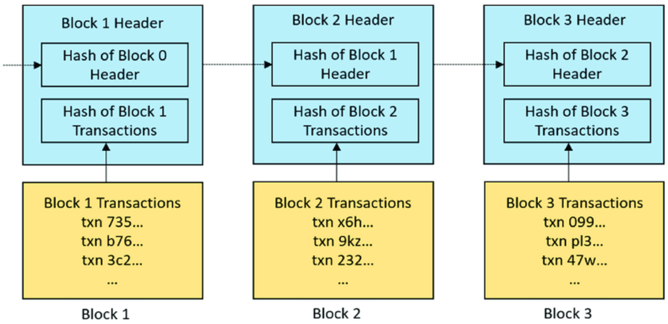

Figure: 1.1: Chaining or Linking of the Blocks

1.1.3 Digital signature

To make a transaction, one needs two addresses, a wallet and a private key. The secret of a private key is a series of random numbers, but unlike an address, the private key must be kept secret.

a) Asymmetric Cryptography

This, also known as public-key cryptography, can be the process of encrypting and decrypting messages using the associated key pair, public and private keys, to protect them from unauthorized access and use.

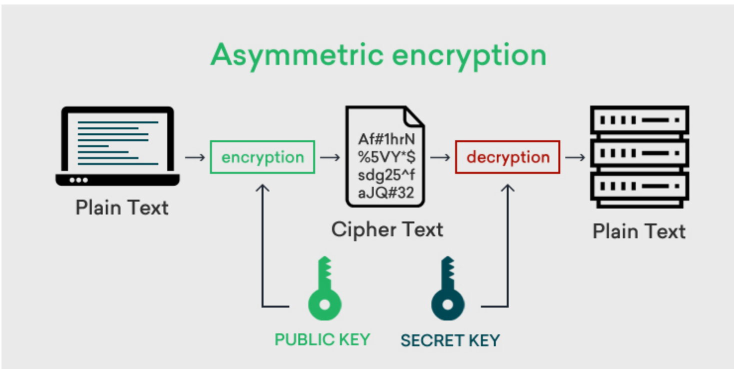

Figure: 1.2: Asymmetric Cryptography

For encryption and decryption, asymmetric encryption uses a mathematically connected pair of keys, as shown in Figure 1.2: a public key and a private key.

1.1.4 Mining

To prevent fraudulent transactions, all transactions will be put to the Blockchain only after it has been validated, as shown in Figure 1.3. Mining on the blockchain is a method of validating new transactions.

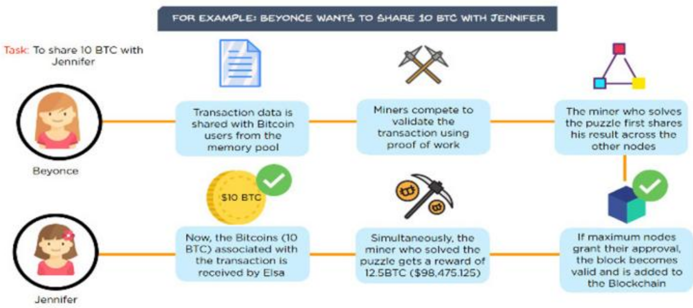

Figure: 1.3: Mining Process

a) Proof of Stake

Proof of Stake algorithms evaluate transaction blocks and request user ratings for particular tokens to gain consensus. Users' staking power is directly associated with what number of coins they lock (on most protocols), and a blockchain may require a minimum number of coins to be staked. Figure 1.4 shows how the proof of stake works and what reward a validator will receive.

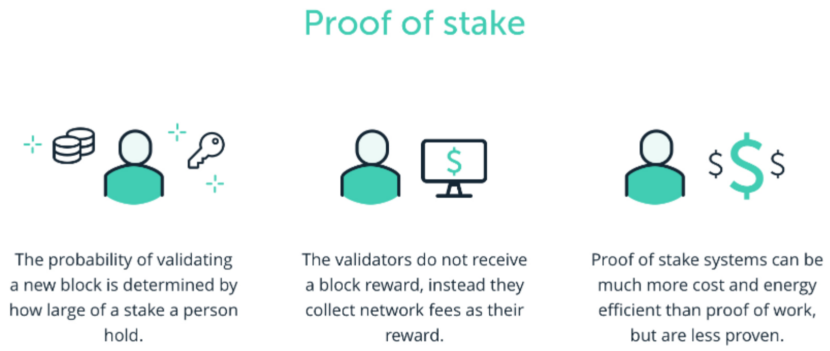

Figure: 1.4: Proof of Stake

b) Proof of Work

A proof of work is a piece of data formed when miners "prove" that they put in resource-intensive work to generate a nonce to verify transactions and add a replacement block of information to the blockchain by solving a block. Miners are rewarded for correctly guessing the nonce if they are the first to respond with a correct answer. A comparison of proof of work and proof of stake based on rewards is shown in Figure 1.5.

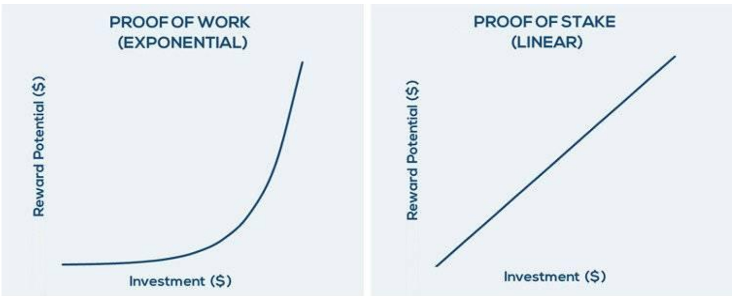

Figure: 1.5: Proof of Work vs Proof of Stake

1.2 Research Motivation and Problem Statement

1.2.1 Research Motivation

Beginning with the invention of electricity the distribution of electricity is centralized. The current centralized method of electricity generation is run by large utilities and energy firms. It comprises a centralised grid where electricity is generated at sizable power plants and transferred to users via a vast transmission network. The problem with this system is that it is subversive since it was believed to be sustainable. Large power plants require more planning and also the infrastructure cost is high, so we need stable energy markets to justify them and it is exposed to vulnerabilities. As the infrastructure and cost of centralized systems vary, providing large amounts of electricity to remote areas becomes difficult.

Centralized power plants can negatively affect the environment in many ways. Some impacts are based on the source of the energy - such as whether the power plant is fossil fuel or renewable. In addition to the impacts of electricity generation, there are also impacts associated with the extraction, production and transportation of certain fuels such as coal and natural gas. There is an opportunity to improve the energy efficiency of power plants, as well as locate power generation closer to end-users to reduce losses in the power supply process.

The increase in demand for electricity has placed more pressure on the global electricity grid and, therefore, the concept of "the grid" could be replaced by a decentralized system. The decentralized energy grids distribute the workload and responsibilities for different infrastructures over several stations. A decentralized system has a faster response, minimal environmental impacts, reduced transmission losses, low infrastructure cost and resiliency against widespread blackouts and natural disasters. To provide transparency, security, data integrity and reliability to microgrid technology, blockchain can be used as it can enable the verification, storing, and transmitting of information regarding the energy transaction in a decentralized way by using a digital ledger that stores all the transactions details with the time stamp.

1.2.2 Statement of the problem

1. Security and Transparency: **-** To provide secure digital signatures, and user authentication.
2. Energy Equality: **-** To make it cost-effective and provide energy to remote areas.
3. UI: **-** To provide a Full Stack Web Platform and to provide an enhanced user experience.

4. Integration of DApps: - Providing data storage, smart contracts and seamless transactions using Ethereum DApps
5. Platform Friendly: - To provide transactions using Blockchain on various platforms and is user-friendly.

1.2.3 Scope of work

1. Ledger System: - Summary of all the transactions for clean and non- tampered transactions history.
2. Peer-to-Peer Trading (P2P): - This is a decentralized network communication model consisting of a group of nodes jointly storing and sharing energy where each node acts as an individual peer.
3. Distributed: - Energy can be generated locally through renewable sources to avoid energy transport losses over long distances.
4. Electric charging stations: - Microgrids can help incorporate charging stations as there is an increase in the usage of electric vehicles.
5. Cost-effective way: - Data storage costs can be reduced by storing real data in sidechains (subsidiary blockchains) and leveraging the main blockchain as a control layer instead of a storage layer.

1.2.3 Objectives of the work

1. Centralized Grids Are Vulnerable: - To avoid having national security issues like infiltration of grids, we use a decentralized system.
2. Power Grid Failures Due to Natural Calamities: - To provide a decentralized microgrid system that can isolate itself from the main grid for an efficient and optimized energy supply to the affected areas during natural calamities.
3. Energy Neutrality: - To reduce infrastructure costs and provide equal opportunity for people to meet energy demands by trading energy.
4. Carbon Footprint: - Using a decentralized system we can reduce carbon emissions by using renewable sources of energy.
5. Reducing Corruption: - To completely remove corruption and mediators in our system.

Literature Survey

During energy trading using Bitcoins, there was a big drawback while trading the energy, the prosumers and consumers are not able to do fast transactions, so to overcome the necessity and huge demands for electricity in a P2P network [5] has introduced Industrial IOT in energy trading. In their previous work, they had worked on a consortium blockchain that was established for decentralised energy trading at moderate costs. To improve the security and reliability of the network, [3] smart contract was proposed that included a scenario with the key functionalities and data needed to handle the auction during the bidding and energy exchange stages. The contract was deployed on the Ethereum network, and the auctions were conducted in a research lab using real PV data and simulated building models to evaluate the auction [3]. For faster authentication [11] used a bloom filter fast query algorithm, they have mainly focussed on describing the privacy preservation techniques used in the blockchain network, to initialise the bloom filter a hashing algorithm is used with the given user's id to map with corresponding values to the array. Since each id value is unique the mapping will satisfy the conditions of the array and authenticate the user. The results showed that the average value and the consumption had a fair selection., the main work was on designing three smart contracts. The main contract facilitates user registration and the storage of all relevant user and transaction information. P2P smart contracts are used to keep local trading between prosumers and consumers running smoothly. The third P2G smart contract allows prosumers and grid energy transfers to continue. For this system, simulations are run, and the results show the goals, energy losses, and PAR reduction. Finally, they created a reliable and efficient energy management system.[4] Helios, a solar energy distribution system controlled by a smart contract on the Ethereum network. From the construction and setup of the devices in the physical layer, which comprised solar panels, smart metres, and batteries, through the implementation, deployment, and testing of the smart contract, the whole architecture of the system was developed. The focus was not to create a trading platform but to verify the practicality of the concept and architecture by examining the system's effectiveness when utilised commercially. The energy grid, the smart contract, and the middleware controller are the three layers of the Helios model. [2] used a simulated experiment for a perfect model of a microgrid in islanded mode, where three generators feed six load nodes. With the physical infrastructure, a new cost attribution model was developed. Using power flow tracing methods, energy transactions between a generator and a load may not correlate to the physical condition. As a result, once a transaction is initiated, a check on physical feasibility is performed to see whether the transaction is viable in the current system. A few energy trading use cases have already been created as a proof of concept. The major goal is to create a decentralised energy system for managing the transactions, such as buying and selling contracts between customers and providers.

One such use case was the implementation of blockchain technology on Predix, an industrial operating system. This was offered as a way to organise the use case around four key components of energy management systems: energy markets, carbon dioxide emissions, maintenance and green certificates. They used honeycomb architecture for blockchain where all microgrids are connected that have energy sources and ESS (Energy Storage System) and Green certificates are used to produce a proof of document that energy is purely engendered from renewable resources. A private chain was chosen as it seemed that the trade-off between availability and consensus could be fine-tuned, making the system more scalable. Corda Testing was used for generating and storing the consumption and production of renewable resources, as a scope of capabilities. A side by the node is used as a notary service to validate transactions [1]. The authors of [15] described the usage of the 57.7% time decrease in a transaction in model 1 compared to model 2 to improve the throughput of the transaction in energy trading. It is undeniable that transactions are faster in blockchain consortiums with optimised transaction permission protocols. It was also discovered that the number of nodes in the blockchain had a bigger impact on transaction performance than the block size. The transaction speed was increased by regulating the number of nodes rather than the block size. To address the challenge related to the architectures of security for the energy trading system [14] implemented a system based on digital tokens with smart contracts that provide extra capability within the operation of the system. In the results, it was observed that it is an efficient system with no errors. From the previous paper, the authors in [13] have mainly researched the multiple microgrid transaction frameworks used in blockchain, like the double auction system, internal microgrids and microgrids etc. In analysing simulation results there have been major improvements in the stability and reliability of the network. As energy consumption is increasing exponentially the necessity for electricity has increased in these past few decades mainly due to the usage of electric cars for preventing the usage of fossil fuels and for the vast development in the energy market using blockchain the authors in [12] have researched on the interconnected multi microgrids technology which provides an efficient solution for sharing energy between micro-grids and the main-grid to enhance the resilience of the system. [9] has researched various use cases of trading of energy in the decentralized network in the energy trading market. The results of the analysis of the use cases showed that there was no disruptive potential and most of the use cases are already achieved using different IT infrastructures. The main focus of this paper is to verify the usage of blockchain in the energy trading market and whether it has enough security and efficiency to handle real-world problems in the market.

As the design of the blockchain is more important in a microgrid technology to provide a more efficient energy distribution to consumers [10] has designed a blockchain network in such a way that the distribution system operator can accept P2P exchanges of energy using a distributed ledger. To make transparency in the system there contains certain rights and duties of each account. The transaction is mainly observed by the neural metering party (DSO). [8] proposed a solution for digital identity management of the prosumers and consumers in the network via smart meters. The architecture of the blockchain is the heart of any energy trading system. Without proper architecture, it may cause a lot of problems like grid failure, power loss, transaction failure, traffic in the network etc. To overcome this [6] describes the development of a new architecture for the blockchain network. They have used smart contracts and Decentralised consensus between non-trusting agents. They have used the “Alternating Direction Method of Multipliers” (ADMM) is used for the optimization of energy networks. They have also benchmarked and tested the network to find out that all the blockchain nodes in an average power consumption had optimal costs and were stable and the system was 80% efficient. They have achieved to decompose the problem of inefficiency of the blockchain and have provided a natural solution for trust, and reliability in the operation of the microgrid, also achieved to avoid the risk of monopoly price manipulation. In this paper, [7] has mainly worked on blockchain and distributed ledger technologies. Their goal was to study and examine the blockchain and its appropriateness in the energy market and argue about the necessity of the distributed ledger in the system. They have also implemented a double auction system which helps in a uniform price mechanism. In this paper, the project is mainly developed using C++ and has done real-time simulation using GridLab-D. The simulation is done by combining the power flow equations.

IMPLEMENTATION

2.1 Methodology

The transaction for peer-to-peer trading is implemented using the backbone of the blockchain which is a smart contract which is developed using the solidity language. These are the self-executing contracts in digital form in simple terms, which contains the contents of the users who are the prosumer-consumers’ agreement and are directly translated into the lines of code. The speciality of the smart contract is that it immediately gets executed when a predefined condition is met as no third party can control this execution nor can it be tampered with establishing trust and transparency.

To collect and store the information during the registration of a member we are using the IPFS which is the IPFS - InterPlanetary File System is a protocol for P2P file sharing. it is used as a distributed file system. It uses content-based addressing as opposed to the traditional HTTP protocol, it uses a content base addressing contents of the file into a fixed-length hash which acts as a unique identifier this method ensures security and reliability.

The contract and details related to the transactions are deployed in the local blockchain ganache in our scenario which is a personal blockchain for the Ethereum-based app development it aids in the development, deployment and testing of the dApp which is done using the Truffle suite framework. The transactions are carried through the Web3 wallet which is mainly the Metamask wallet which enables the users to access the Web3 ecosystem of decentralized applications.

To implement the frontend system, we have used the React.js framework which is one of the popular frameworks due to its dynamic behaviour and for enabling the browser to communicate with our Ethereum local blockchain Ganache the JavaScript library Web3.js is used. Using react makes it a dApp with good UI and aids the users in terms of intractability and making hassle-free trading.

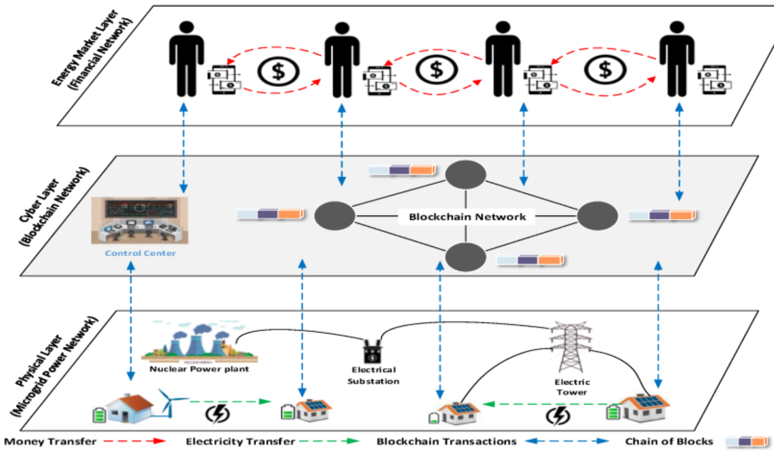

Figure 2.1: Methodology

DESIGN

3.1 Architectural Design

The Architecture Design consists of five layers as shown in Figure 3.1.

1. Application Layer: The application layer mainly comprises DApp, Front-end and Smart Contracts. The Application layer is separated into two layers:
    a. Application layer
    b. Execution layer
    c. The first layer is used by the users to interact with the blockchain network. It helps to view the list of all the available energy devices and other useful information needed for the blockchain network. The blockchain network acts as a backend network for the application. The second layer contains all the smart contracts, chain code and underlying rules. A transaction starts from 1st layer to 2nd layer and is confirmed at the semantic layer.
2. Consensus Layer: It is mainly used for validation and ordering of blocks, the consensus algorithm used. By using the consensus algorithm, we can achieve a P2P network. It helps to create a set of agreements between producers and consumers in the network. This layer also guarantees that the transaction is validated within the boundaries of the rules provided.
3. Network Layer/Blockchain Layer: In this layer validation of blockchain takes place and stores all the transactions in the form of blocks. Since the P2P layer helps to discover each block, it helps to maintain the network's workload and helps for verification and authenticity of the blocks.
4. Data Layer: This layer deals with the data storing and handling which consists of the ledger, hash, digital signature, and transaction details.
5. Component Layer: It deals with the components such as photovoltaic devices. Example: Solar Panel, Windmill etc.

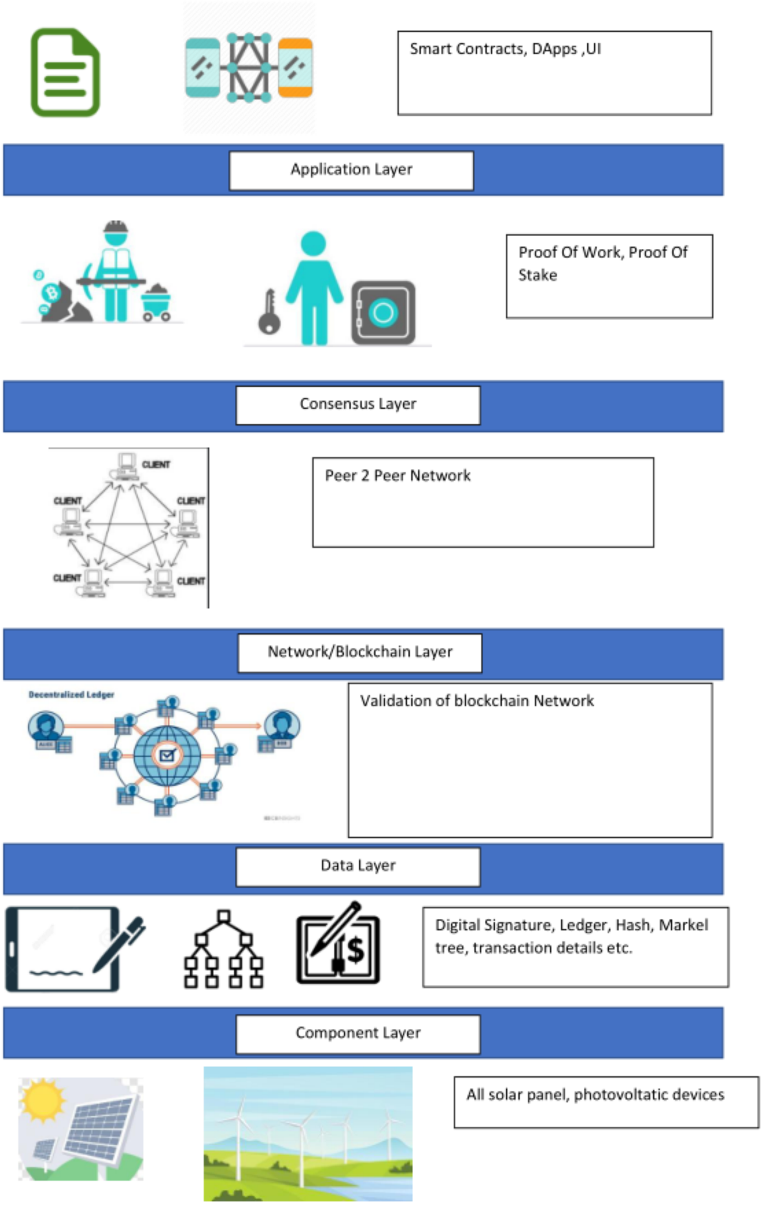

Figure 3.1: Architectural Design

3.2 Class Diagram

Figure 3.2 explains our system with 7 classes which are explained below:

- A marketplace class with attributes consisting of the details of consumer and producer, the price of the energy, smart contract, timestamp and specific functions to get prosumer and consumer details, smart contract and the status of the utility. This class also has an association with the Utility class and a dependency on the Blockchain network class.
- Utility class has attributes like energy produced, load, type of resource and functions for getting the load, the energy produced and status of the marketplace.
- Consumer class consists of details regarding the consumer and is dependent on marketplace class for getting the contract details and availability.
- Prosumer class is similar to consumer class but has the details of the producer. It also has a dependency on the marketplace class for setting energy limits and deploying contracts.
- The most important class is the blockchain network class which has attributes that are necessary for a block to be created and functions for proof of work, chain validation etc.
- Two other classes namely, block and transaction have a 1: n relationship with the blockchain class which as the name suggests has information about the block and transaction respectively.

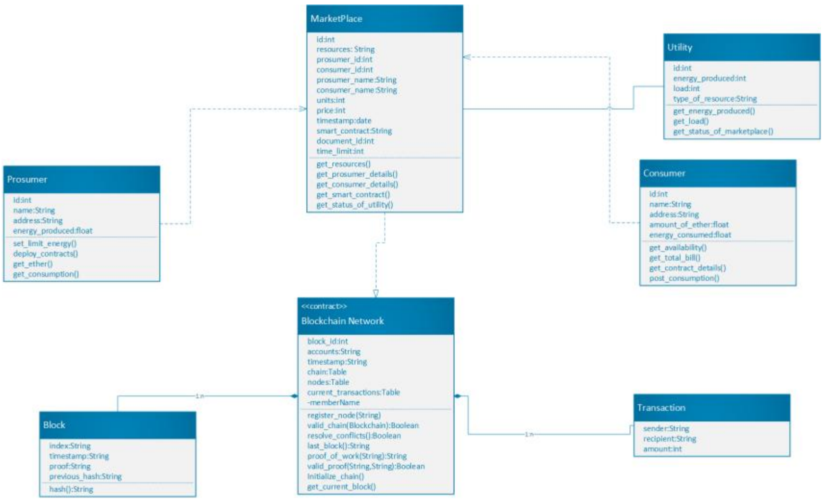

Figure 3.2: Class Diagram

3.3 Sequence Diagram

Figure 3.3 is the same for our work too. The Prosumer object registers in the marketplace for which acknowledgement is generated. The marketplace object starts by entering the bid details into the blockchain and the acknowledgement for the same is generated in return. The marketplace also collects the total number of bids from the blockchain object. The prosumer object publishes the energy and the bid details which the consumer object will later get for purchase. A bill is generated for the consumer which completes the process for the consumer. A utility object is used to get the utility details and complete a handshake.

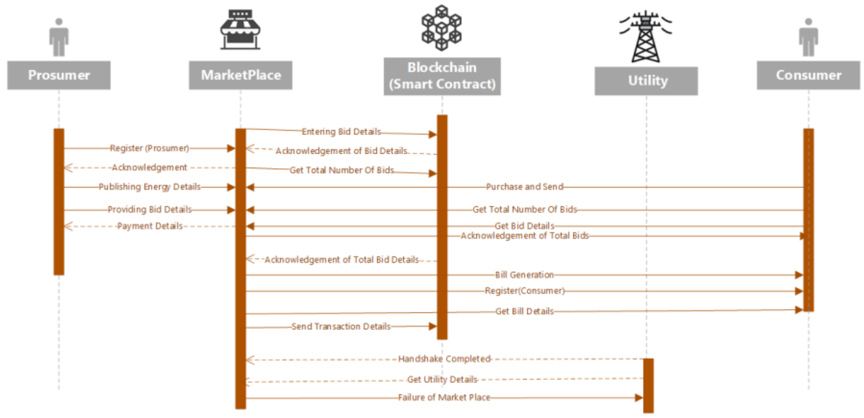

Figure 3.3: Sequence Diagram

3.4 Use Case Diagram

Figure 3.4 shows three main actors namely prosumer, consumer and smart meter. The prosumer initially deploys the contract on the blockchain network. Consumers define the required amount of energy and are in turn checked for availability in the auction system. Once accepted by the prosumer, the transaction is verified, added to the ledger and sent to the consumer through the smart meter.

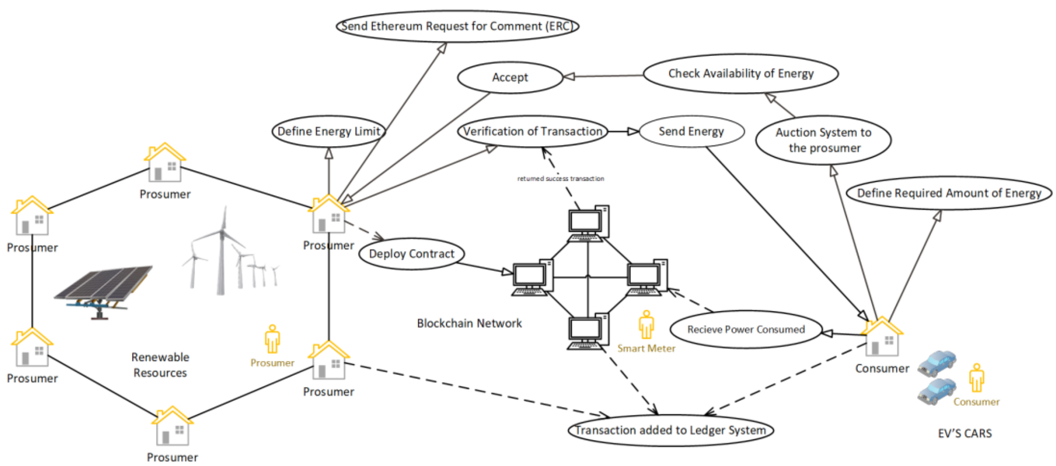

Figure 3.4: Use Case Diagram

RESULTS

Figure 4.1 represents the consumer page which contains all the details of the energy available in the market. It provides the details of the energy agreements and provides an option to sign the agreement.

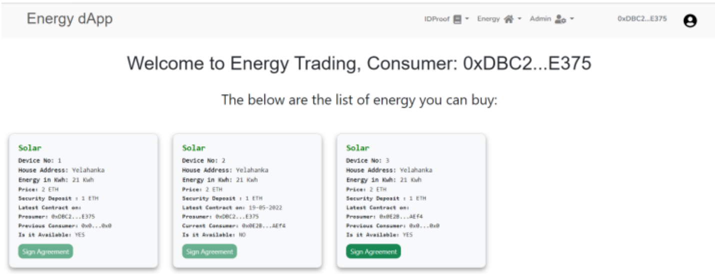

Figure 4.1: Consumer page

Figure 4.2 represents the prosumer page where the details of the contract are provided and verified and pushed into the open market. The prosumer can delete the device and disable it for maintenance.

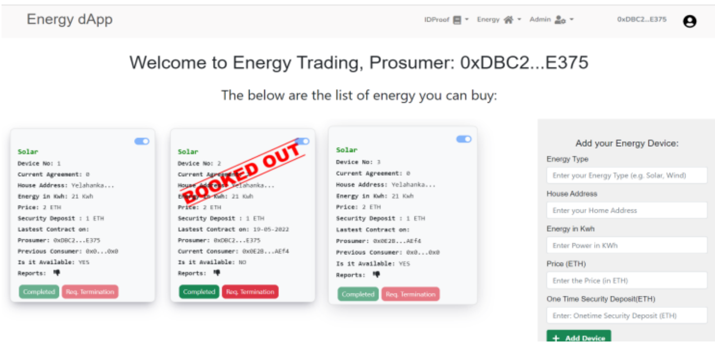

Figure 4.2: Prosumer page

CONCLUSION

The work carried out uses Blockchain technology for trading energy using the concept of microgrids for the source is a decentralized application which encompasses a smooth user-friendly user interface which makes it a responsive application to use. The work makes use of the blockchain's properties which provides the solution to the security as it uses the concept of cryptography for storing the transactions and by making use of the consensus mechanism it makes the transactions more transparent and immutable, the microgrid which acts as an agent in reducing the carbon-dioxide emission by using the renewable is in a distributed manner is easily managed by the application as blockchain involves the concept of distributed decentralization through which every consumer can become a prosumer to buy/sell the energy which encourages people to set up more renewable energy sources as they can earn through that which in turn helps the environment as by reducing the carbon dioxide emissions and thus reducing the trap of greenhouse gases which will be a crucial step in stopping global warming. The usage of microgrids enables us to provide energy to all areas including the remote areas by reducing the transmission losses which makes it accessible to everyone.
The design and the smart contract used to develop this work enables users to carry out the transactions in a hassle-free manner.

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