Block Chain Technology based Energy Trading in Smart Grids

A REPORT

Submitted by

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CERTIFICATE

This is to certify that the thesis titled **BLOCK CHAIN TECHNOLOGY BASED ENERGY TRADING IN SMART GRIDS**, submitted by **GALIMURI ARUNKUMAR**, to the Indian Institute of Technology, Madras, for the award of the degree **of Master of Technology**, is a bonafide record of the project work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

Smart grid systems have gotten famous and vital for the advancement of a sustainable power grid. For ideal and continuous power utilization, monitoring and exchanging, block chain have number of expected benefits in its application to power framework. A blockchain-based smart grid model is proposed and energy exchanging is executed between Distribution System Operators (DSO), Local energy suppliers and Consumers.

The studies are mainly focused on smart contracts, and mining process and how they facilitate and support transactions in smart grids. Energy sharing is a hot topic as a consumer being a part of the sustainable distributed system also making benefits such as Prosumer. This report presents a virtual smart grid model equipped with smart contracts.

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CHAPTER 1

INTRODUCTION

Today, the requirement for the power in the energy area is on the ascent like never before. The force age is unavoidably moving towards sustainable power sources. Wind and sunlight based energy appear to be the predominant giver among all fuel sources and has all the earmarks of being the case even later on occasions. The customarily assembled smart grid network isn't fit for tending to various difficulties. The primary test is the expansion of another element which is knows as prosumer which can create and burn-through energy [2]. As world jumps forward towards development and innovation, smart grid become a fundamental part to handle recently arising issues. Smart meters, bidirectional energy stream and advanced stages for decentralized market instrument are not many of the numerous highlights which can conceivably be taken care of by smart grids. Smart grids furnished with these qualities can then profit prosumers and customers with more complex energy observing and improved energy stream and exchanging.

The presentation of the Internet of Things (IOT) and smart cities with smart homes will alter the whole computerized world. As we move towards the eventual fate of smart cities, smart grids assume a suitable part in building a computerized heaven. A strong power grid network controls information and energy stream as well as gives a spine to safer, quick and adaptable grid platform. Smart grid offers an answer for coordinate all the fuel sources and spotlight on working with local energy production.

Customary advanced administrations, gadgets and applications work under concentrated pecking order. The general control of the design lies under single point substance. There was a sure hole for decentralized designs with conveyed control. To adapt to exchanging exchanges among shoppers and prosumers partaking inside smart grid plainly requires a decentralized framework [3]. Block chain can possibly change the customary brought together frameworks. This innovation gives a stage to multi-nodes peer to peer organization rather than single gathering control which will permit decentralized application to aggregately work under unknown nodes.

Digitals cash was the first blockchain based decentralized application, begun under the name Bitcoin which exists as advanced money and furthermore known as digital currency. In 2008, the possibility of blockchain alongside Bitcoin was presented by an obscure personality under the alias Nakamoto. He distributed the Bitcoin white paper which established the framework for other shared electronic

money frameworks [4]. Since 2009 Bitcoin and other comparative advanced installment strategies have showed up under the domain of blockchain innovation.

Blockchain alongside digital money had slight disadvantage with regards to decentralized frameworks. The introduction of smart contract is a forward leap for taking care of frameworks without central authority .Smart contracts empowers us to send completely self-governing, peer to peer platforms, which can eventually dispense with the job of any third party.

The genuine utilizations of blockchain began to arise after the presentation of the smart contract in 2013 [5]. smart contract is a subjective piece of program code which is executed on network nodes appropriated over a stage. Its attributes like client characterized determined principles, self-execution and written in high level programming languages permit us to make decentralized administrations, applications, associations and market systems. The main part of the fundamental blockchain innovation is to be utilized as an apparatus for uniquely made cryptocurrency, computerized resources and complex applications permitting clients to show any self-assertive conditions. Henceforth making blockchain-based decentralized autonomous organizations (DAOs).

Ethereum was the first blockchain-based convention to present smart contracts in 2015. It gives an intelligent stage by utilizing a theoretical establishment layer to convey smart contracts composed with an implicit Turing-complete programming language to create secure, cost effective and smart applications with client characterized rules [6].

Blockchain innovation establishes the framework for decentralized business sectors, insightful computerized resources, Smart autonomous agreements (Smart contract) and the most popular one is decentralized digital currency. Its far reaching organization permits advancement of administration strategies without intercession of any outsider, with everybody in framework consenting to a democratic consensus mechanism [7].

Because of fast expansion in the environmentally friendly power assets, there is a fundamental requirement for the development of the customary energy disseminated framework into stronger and sagaciously improved energy networks. One of the critical components of a smart power grid is to acquaint peer-with peer energy (P2P) exchanging stage [8]. P2P energy exchanging can additionally prompt more advantages, for example, user preference energy sources, strengthening to partners instead of a central authority, consensual market mechanism and expansion in the general limit, can demand request reaction, blackouts and other power grid complications.

1.1 PROBLEM STATEMENT

As we move towards the time Internet of Things (IOT), the advancement of smart cities will be the following large test. With the presentation of trillions of intelligent devices self-governing constrained by ideas like distributed computing, edge figuring and so forth, makes a requirement for enhancing the information utilization by presenting smart and intelligent machines. Alongside the smart devices, energy market application additionally should be tended to.

The endeavor in this proposal, is to investigate the presentation of smart grid fit for supporting an independent energy market utilizing blockchain as establishment layer. It clarifies intentions in creating blockchain-based smart grid and potential limitations and issues in regards to the energy appropriations.

DAOs utilizing blockchain as a middle person, generally brings about costlier stages than ordinary methodologies. The formation of blocks and throughout all defer time amounts to unreasonably expensive conditions. The improvisations are examined and the room for streamlining is the principle subject of this proposal.

1.2 THESIS STRUCTURE

The master's theory is organized as follows. section 2 contains writing survey for smart energy markets and how they can work with sustainable power sources.

It further clarifies blockchain as a distributed ledger and its types and protocols. Digital forms of money, Ethereum, smart contracts are described. These ideas are important to comprehend and to break down how blockchain-based energy markets can be created.

section 3 is plan and execution of a virtual smart grid for performing core functions of a smart grid. The endeavor gives bits of knowledge from an innovation planned of how smart contracts and Ethereum performs.

section 4 offers potential commitments for future work and examine ends drawn from looking this method while conveying smart grids utilizing blockchain.

CHAPTER 2

LITERATURE REVIEW

This section gives inside and out audit and clarify the fundamental ideas needed for the examination of the blockchain and its application in regards to smart grids. The connected work, ideas, phrasings and late genuine applications have been talked about. It likewise gives brief outline of future work and various methodologies completed in smart grid area. A systematic blockchain study is performed and its likely advantages alongside ongoing execution cases have been talked about in this section. A case study investigation is characterized with inspiration of giving applied information in regards to blockchain-based smart grid domain.

2.1 Block chain technology

Blockchain is a unique sort of information structure which performs and stores transactions in blocks. Each block is associated with a pervious block with a timestamp and a hash link. Blocks give unaltered information records and can't be changed reflectively. It is to be considered as a distributed sort of information base where entities which don't trust each other and where there is no single place of control. The members can depend on each other completely decentralized [10].

Blockchain can be essentially characterized as a record as a chain which is built with numerous blocks. Besides, because of the way that blocks can't be changed without changing the total chain of blocks, which makes the system stronger and making it more hard for the attacker. To change the current block, all previous blocks must be adjusted. This makes blockchain innovation a safe strategy for moving computerized helps, cash and agreements without including any third party agents.

During digital occasions among the taking participating entities, blockchain goes about as a public record, all things considered. The way toward making another block is called mining. A consensus is held among all nodes to confirm each block which guarantees integrity and trustworthiness.

Blockchain empowers a distributed platform between the participating entities where the agreement is held in a democratic way. This can upset the computerized world in financial and non-financial areas. Blockchain based frameworks are assembled utilizing many associated nodes and many programming languages are right now used to fabricate the blockchain network. The most well-known one and utilized in this proposal is Solidity and java and Go [12].

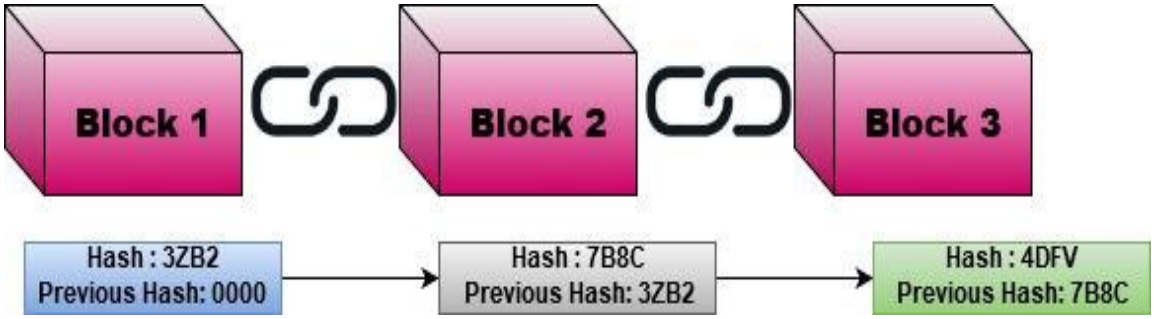

Figure 1. Blockchain block diagram

Figure 1 addresses the basic blockchain arrangement. The first block in every blockchain network is known as Genesis Block. The block contains data and a hash which uniquely distinguishes each block as demonstrated in Figure 1. Each block additionally contains hash of the previous block as outlined in Figure 1, which acts as a security layer on the grounds that an adjustment in single block outcomes in invalidation of subsequent blocks [13].

2.3 Smart contracts

A smart contract is a computer code running on top of a block chain containing a set of rules under which the parties involved in that smart contract agree to interact with each other**.**

Figure 2. Smart contract diagram

Smart contracts are simply programs put away on a blockchain that run when predetermined conditions are met. They generally used to automate the execution of an arrangement so that all participant's members can be quickly certain of the outcome, without any intermediary's involvement or time misfortune.

2.4 Consensus mechanism and types of block chain

Block chain's principle ensure for security is the utilization of hashes, anyway attackers can still use very expensive and super-fast computers recalculates every one of the hashes and this can penetrate security layer. To defeat the issue, the process of consensus among the blockchain nodes is introduced [17]. The most notable consensus mechanism utilized in blockchain are:

- ***Proof of Work (POW):*** The main idea behind POW is that it is a kind of a hashing rivalry between the nodes of the network to ascertain a mathematical problem. Miner nodes attempt to take care of the math's problem and whoever will settle it initially is the person who makes the next block. Miners choose which new block will be added in the blockchain. Most normal models are Bitcoin and Ethereum [18]. Not a much enhanced method of executing agreement system because of the way that it requires an enormous measure of computational power which itself is a vital resource while planning a keen framework. POW boundaries incorporate a hash capacity and block generation time. Block size is the most important parameter of POW but increasing the size of block will also increase latency [10].
- ***Proof of Stake (POS):*** Approval of the block relies upon approving elements and their stake (how much the stake node has contributed) in the formation of the block. The idea can be clarified by taking the case of coin age (time made and the worth of a digital cash). The security of the blockchain is expanded because of the worth added by coin age and it is done relying upon POW which at last additionally settles the wastage of extra computational force [18].
- ***Delegated Proof of Stake (DPOS):*** A block is produced after each individual from the blockchain network votes to choose delegates and various observers. The idea depends on distributed voting. The N number of witness are chosen and at any rate half of the partner's consent to decentralization. In the event that the observer can't create another block, the information will be annexed in the next block and partners will cast a ballot and assign another observer to replace it. The algorithm appears to be more powerful than PoW and PoS both [18] [19].
- ***Practical Byzantine Fault Tolerance (PBFT):*** Generally utilized in trusted or semi-confided in conditions and dependent on calculation which requires 2/3 of the organization nodes to consider the exchange legitimate and really at that time it is added to the ensuing block [19]. Hyper ledger utilizes PBFT calculation as its consensus model. PBFT is the most improved model of the consensus calculations where complexity is nearly decreased to polynomial level.

Blockchain can be classified in the following types:

- ***Public blockchain***: A blockchain where everybody has perused admittance to the blockchain and may submit exchanges to it, for example, Bitcoin and Ethereum [20].

- ***Private blockchain***: A blockchain in which just substances remembered for a predefined list can peruse the blockchain and submit exchanges to it, for example, Hyper ledger Fabric [20].

- ***Permission-less blockchain***: A blockchain in which there are no limitations to who is permitted to make blocks [20].

- ***Permissioned blockchain***: A blockchain in which characters, just remembered for a predefined list, are permitted to make blocks [20].

Figure 3 shows the order of blockchain architecture. All web clients are permitted join Public Permission-less records and can likewise be essential for the approval process. In this kind of architecture, clients and validators are generally obscure to one another and subsequently require a reliable administration framework [19]. In the opposite, in Private Permissioned records the entrance is limited to just approved and referred to clients, comparative as know-your-costumer (KYC) idea. This makes the framework more versatile and quicker [19].

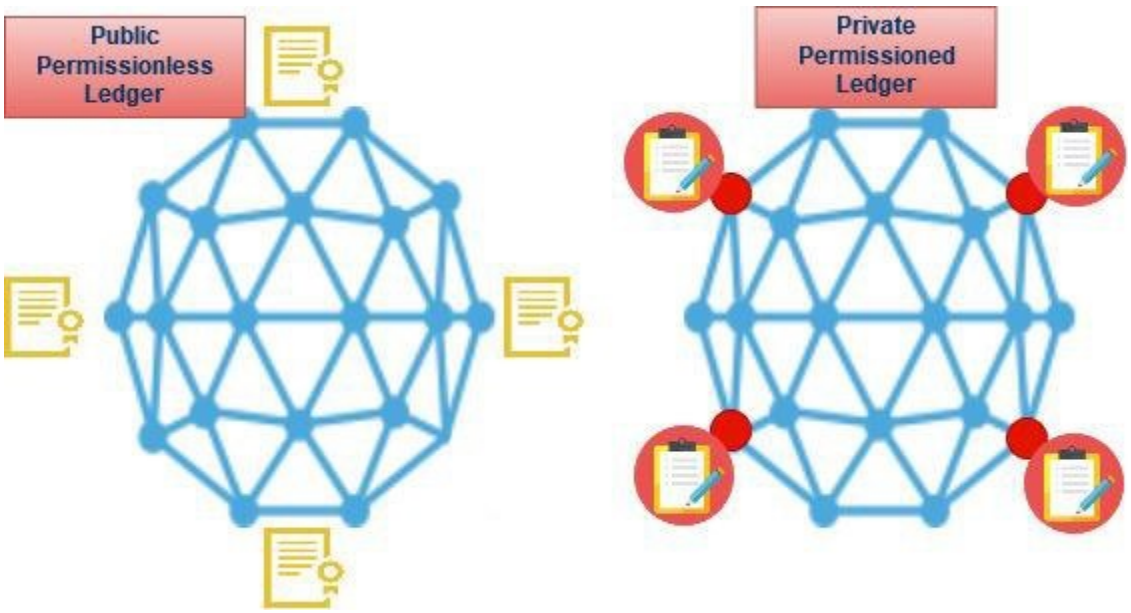

Figure.3 Types of block chain architecture

2.5 Evolution of Blockchain Technology

In development of smart energy supply, a smart grid ought to be equipped for self-keeping up, self-redressing, exceptionally powerful and ongoing valuing with conveyed energy management system.

Skill of various designing perspectives are needed to cooperate to assemble a productive smart grid. Various logical and mechanical progressions have been done are at present there are numerous continuous ventures identified with smart grid.

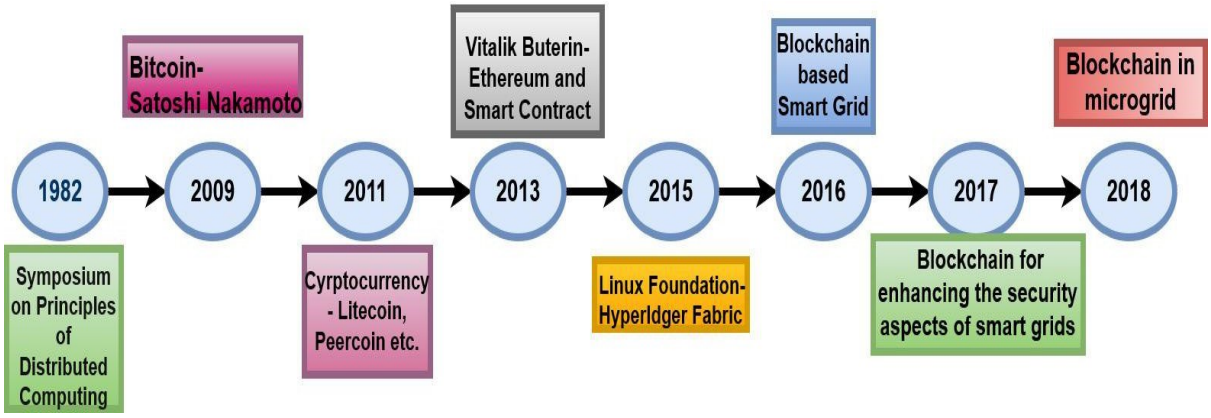

Figure 4. Evolution of Blockchain technology

Very much like many arising advancements, blockchain has its own course of events which is shown in Figure 4. Blockchain is obviously a result of numerous advancements joined. The primary conference on Principles of Distributed Computing was held in 1982, which established the framework for creating blockchain innovation right around 30 years ahead in future. The main genuine picture of blockchain was introduced by Satoshi Nakamoto in 2009, with his white paper "Bitcoin: A Peer-to-Peer Electronic Cash System" [4]. Since 2011, numerous new digital forms of money are constructed utilizing blockchain as basic innovation. The genuine execution of the blockchain applications began in late 2013, after the presentation of smart contracts. This changed the blockchain based applications yet there was as yet a requirement for more versatile and adaptable stage. Linux establishment acquainted Hyper ledger in 2015 with tackle versatility and security issues. From that point forward, energy area began utilizing blockchain as a promising innovation to change traditional grid framework into smart grids.

2.6 Motivation

The true spirit and the worth to any innovation lies in meaning inside its prosperity and good scene. The utilization of drove in gas was the most community method of delivering modest fuel, back in the year 1900. For right around 65 years' businesses would not concede that more elevated levels of lead are risky to people. Consequently, embracing arising advancements for accommodation isn't the solitary point yet in addition to protect the climate and support the eco-framework.

CHAPTER 3

BLOCK CHAIN BASED SMART GRID MODEL

Ledgers have been in need for quite a long time and has been demonstrated to be an extremely proficient method of recording and bookkeeping exchanges. With blockchain innovation, the idea of advanced permanent record is a distinct advantage in monetary area. Smart grids utilizing blockchain coordinates impeccably with the qualities needed for upgraded energy market. With the assistance of blockchain, disposing of the focal substance and disseminating power among the partners, opens the chance of an alternate and proficient trust model.

Modern grids (smart grids) joined with computerized monetary forms, for example, Ethereum can prompt a quicker and more strong answer for power issues in such conditions and outrageous conditions. All current exchanges are set in accessible blocks, which structure a tuple of exchanges that are timestamped and sequentially binded to one another, framing a blockchain. The blockchain-based framework gives a conceivable answer for empower such grid plans. The virtual exercises, for example the market mechanism and payment function, are both directed on the blockchain [31]

3.1 System architecture

As of late, different strategies have been proposed to assess shrewd network execution utilizing blockchain. In Figure 4, we represent the overall design of a blockchain-based brilliant framework.

Figure 5. Block chain based Smart grid

The proposed framework design depends on powerful ongoing power utilization utilizing blockchain as an arbiter. Keen meters fill in as administering bodies to control information and give admittance to clients to checking their power conduct. Smart meters go about as passageways for the decentralized blockchain-based smart grid.

The reason for the segment is to clarify the smart grid components and how to create energy-based commercial center for bi-directional energy stream and exchanging. The self-governing energy market is constrained by smart contracts.

Smart contracts capacities are to assemble and coordinate helpful attributes of the energy market and to carry out following tasks:

1. Smart grid offers purchasing and selling of energy utilizing cryptographic money.
2. Blockchain alongside smart contracts go about as self-sufficient third part to guarantee dependability.
3. Smart contracts give capacities like balance enquiry, payments and adding new customer.
4. Current smart grids need directing guidelines, Smart contracts based blockchain offers potential decentralized energy arrangements which are helpful in following energy as well as carbon footprint.

The design introduced in Figure 5 permits smart grid members to effectively exchange energy utilizing blockchain as third party as opposed to depending on a solitary focal power (already as banks or energy supplier). This gives a stage to transparent commercial center between the suppliers and customers. Since the central entity is presently blockchain, smart contracts guarantee honesty for deposits, exchanging of the energy and go about as leader between energy suppliers and consumers.

In addition to market mechanisms, block chain gives a stage to present micropayments utilizing digital money. Block chain's convention Ethereum utilizes 'ether' as its acquired installment stage. Also, we have micropayments in practically all the blockchain conventions for managing exchanges over blockchain network.

3.2 Energy trading process

The cycle of energy exchanging utilizing blockchain-based virtual smart grid is portrayed in Figure.5. The virtual smart grid comprises of different entities and components. As right now dominant part of the stake in energy markets are the

distribution system operators (DSO's) and an extremely modest quantity of local energy suppliers. Because of smart meters' trait of bi-directional energy stream, nearby supplier can send extreme energy back to the grid. The way toward executing energy between the prosumers and the customers is effectively constrained by blockchain rather than the DSO's.

The purchasers can be consumers or the prosumers (in the event of local energy suppliers). sale and purchase understanding is performed between the buyer and the seller utilizing smart meters outfitted with smart contracts which guarantees terms and conditions are met to continue the exchanges. Every one of the exchanges are put away in the blocks produced during the mining process. A timestamped information for every one of the exchanges and questions is put away inside the blocks and blockchain ensures that information can't be changed.

In the proposed architecture is appeared in Figure 5, smart meters go about as miners to produce a blockchain exchange. The smart meters and the smart contracts between the parts of the grid, go about as overseers to ensure any unapproved energy utilizations are denied. Smart contracts choose which exchanges are endorsed and starts comparing information works independently. The in general blockchain framework in a virtual smart grid is at first conveyed by DSO's.

The framework's respectability is protected by blockchain and its miners which for this situation are smart meters introduced at local energy suppliers and consumers.

Virtual smart grid components and their comparing capacities inside the network are likewise talked about in this part.

3.3 Distribution system operators(DSO)

DSOs go about as middle people and are answerable for exercises like market mechanism, payment function for the two consumers and local energy suppliers. In view of the information from comparing blockchain accounts (consumers/prosumers), DSOs guarantees private data protection and installing and maintenance of smart meters. DSO additionally go about as a miner inside the blockchain organization to guarantee agreement all through the market.

Since the job of DSO's in regular energy trading system was a centralized authority and they were the only administering bodies controlling all the market functions. Presenting blockchain won't just supplant the centralized authority position yet additionally guarantee a reasonable and simply market stage to urge new customers to act local energy suppliers and henceforth making a decentralized and unbiased energy market

3.4 Local energy providers

Local energy providers produce the energy utilizing sunlight based, wind, biogas, and so on and infuse energy into the smart grid. local energy suppliers additionally go about as miners in the blockchain to guarantee the consensus and henceforth carrying out the idea of the decentralized market.

The mechanism depends on micropayment, measure of energy infused is correspondingly compensated with indicated tokens utilizing smart contracts which permits exchanges over the blockchain network when certain conditions are met.

3.5 Consumers

Consumers follow through market price and go about as nodes in the blockchain layer. smart meters are introduced in each house. smart meter readings are recorded in blockchain network utilizing smart contracts. Consumers can purchase power utilizing determined tokens, either from local energy supplier or DSO.

3.6 Smart grid characteristics

The proposed architecture expects that every one of the clients are interconnected to the grid through smart meters. Figure 5 represents the connectivity among all members. Smart meters permit clients to sell or purchase energy utilizing micropayment functions. DSO's ensure that only legitimate smart meters are permitted to join the blockchain network.

Smart contracts permit consumers to purchase energy when a payment function is executed. Essentially, local energy suppliers likewise utilize smart meters to sell energy and the payment function ensures that the transactions are finished. DSO's actually have most of the stake, so they are responsible for all the off-grid functions like establishment and maintenance however are not, at this point the only central authority since local energy suppliers are likewise important for the consensus before the data is put away on the blocks.

3.7 Grid architecture flow

The following steps are represented in Figure 5:

1. DSOs convey a blockchain-based network and introduce smart meters with smart contracts.
2. Consumers utilize smart contracts to enlist and makes a record over the blockchain based network. Each client will have unique address and client profile.
3. Smart meter information is sent over blockchain network and can't be changed. (Blue lines)
4. Local energy suppliers alongside DSOs go about as miners to guarantee honesty and consensus mechanism among members, subsequently accomplishing decentralized market component with no central authority.
5. Token-based exchanging system is utilized for buying and selling of energy. (Golden lines)
6. DSOs are likewise answerable for delay-tolerant data. Adjusting the grid load, overseeing client's profile, billing and maintenance.

CHAPTER 4

IMPLEMENTATION ON ETHEREUM

This section gives the execution subtleties of the Blockchain based smart grid utilizing Ethereum. The proposed architecture exhibits the framework plan, with the smart grid execution over a permission less Ethereum blockchain.

4.1 Architecture

Figure 6 shows the arrangement of the framework with DSO, three local energy suppliers as three miners and three ethereum full nodes as consumers.

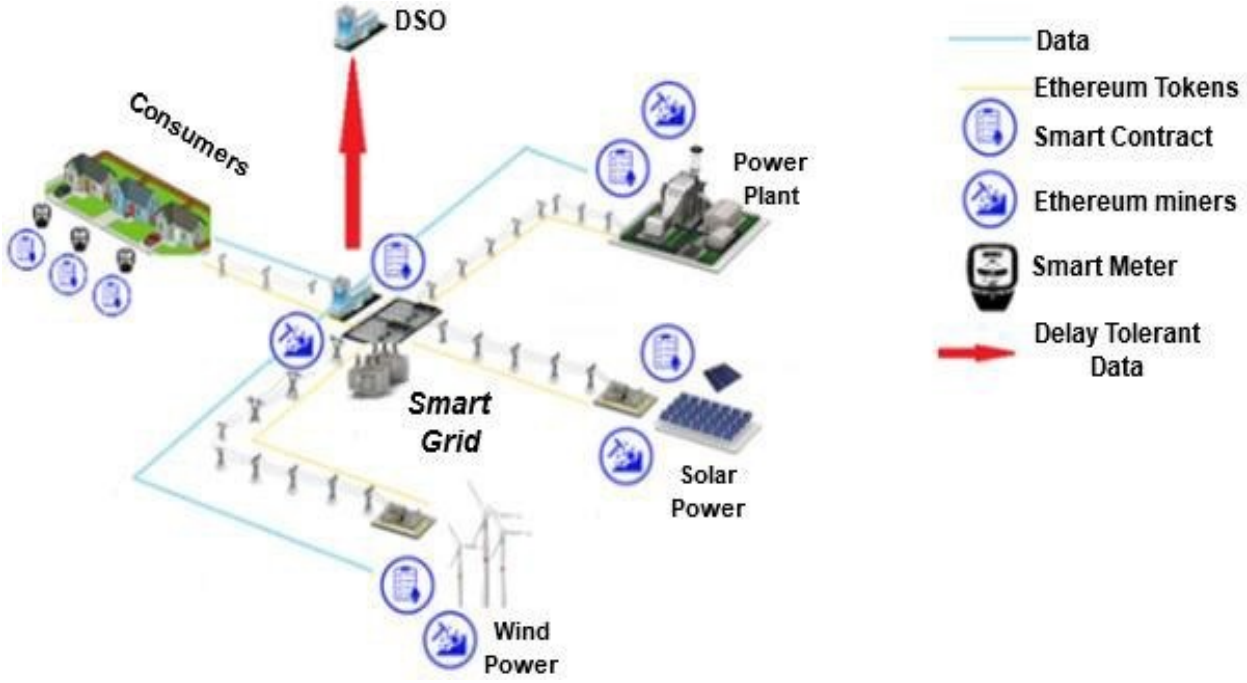

Figure 6. Blockchain-based smart grid using Ethereum

4.2 Mining process

Figure 6 represents the various sorts of local energy suppliers, for example, solar powered, wind, and biogas. Local energy suppliers are prosumers and they have bi-directional energy stream. In the proposed framework, the miners are local energy suppliers and DSO, that produce a block of exchanges in 15 seconds during the mining process, thus carrying out an consensus mechanism by utilizing Proof of Work. Mining rewards are moved to Ethereum wallets, doled out to all the prosumers. Likewise, consumers additionally have wallets for their energy use. Each exchange is put away in the blocks for consumers and prosumers and market payment system is conveyed utilizing Ethereum tokens.

4.3 Transaction and Fee system in Ethereum

An exchange in Ethereum is the data package endorsed by the outside claimed account. An Ethereum exchange contains the measure of ether, beneficiary of the message STARTGAS, GASPRICE and optional information field [15].

The STARTGAS and GASPRICE fields are expected to forestall accidental or antagonistic loops and are fundamental line of safeguard to forestall denial of attack. An exchange expense is the quantity of computational strides of code execution. Its fundamental unit is 'gas' and is utilized to compute transmission capacity and capacity assets an exchange can ingest [15].

Ethereum's exchange can consume gas by numerous ways. Each exchange performed over the Ethereum has a base expense worth of 21,000 gas. At the point when an exchange is performed for the organization of smart contract, it has a gas cost contingent upon the intricacy of the smart contract [15]. The absolute expense of any exchange whether it's a question or execution of the smart contract is really the measure of gas consumed.

4.4 Virtual smart grid using Ethereum virtual machine

Ethereum virtual machine (EVM) is a virtual stage where smart contracts are executed. The upside of utilizing EVM is that there is no hardware requirement and gives indistinguishable settings to arrangement the total blockchain network.

EVM offers JAVASCRIPT VM environment utilizing https://remix.ethereum.org [32] and each task executed in EVM is approved by each Ethereum full node. Smart contracts are then executed by the nodes.

A blockchain-based virtual smart grid was carried out utilizing EVM and smart contracts were conveyed for executing smart grid usefulness. Figure 7 is a pictorial perspective on the EVM environment.

Smart contracts written in high level programming language 'Solidity' alongside compiler form '0.4025+commit.59dbf81.Enscriten.clang'was utilized to send Ethereum based blockchain network.

The smart contracts conveyed for our situation have the most extreme measure of gas limit 3000000. As examined over each exchange has a base. The exchange cost of the smart grid contract was 675585 gas and the execution cost were 471529, as demonstrated in Figure 10.

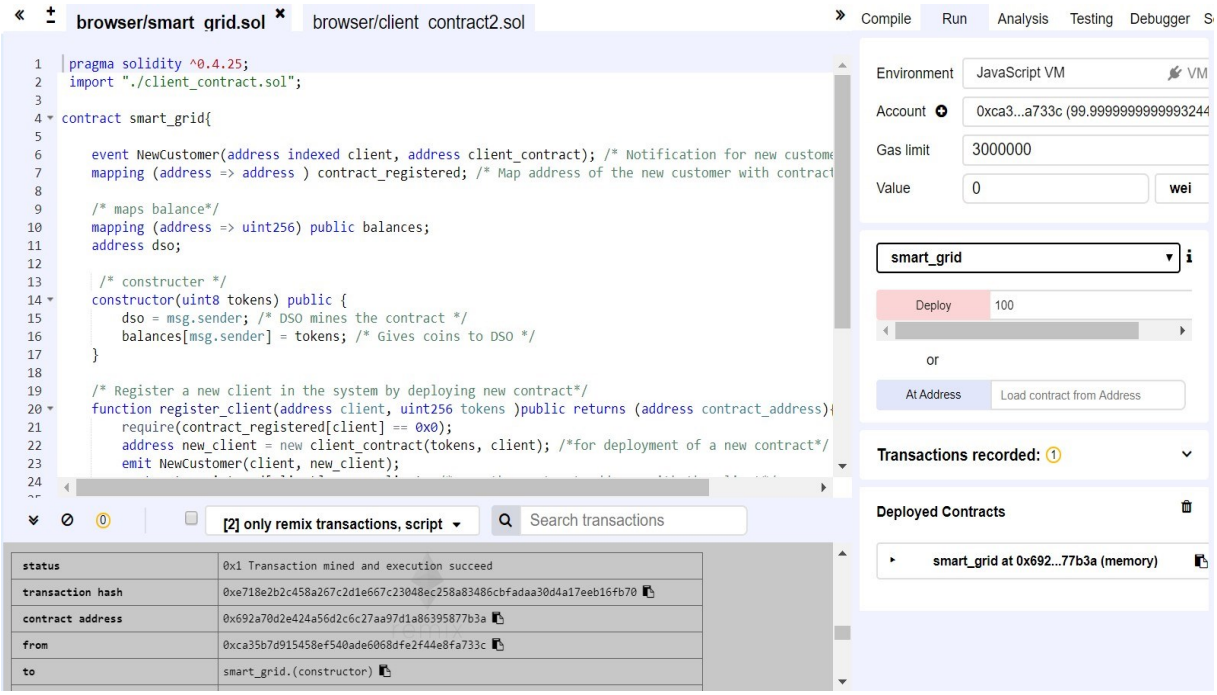

Figure 7. Virtual smart grid using EVM

4.5 Smart grid contract description

Figure 9 addresses the perspective on the virtual smart grid, build using EVM and smart contract (additionally accessible in Appendix 1). After the contract is sent a unique address is appointed to DSO. Figure 8 outlines the essential calculation utilized for different DSO functions which it can perform.

Algorithm Smart Contract

mapping (*address => uint256*) **balances**

Init: address DSO

constructor (*Token, NewCustomer*) **:**

| balanceOf[DSO] = InitialSupply

Event NewCustomer (*address,amount*) **;**

Function registerClient (*address*) **:**

| **return** addressOf[Client]

Function getClient (*address*) **:**

| **return** addressOf[Client]

Figure 8. Algorithm for smart grid contract

1. Line 1 pragma which tells the compiler that this contract is composed for solidity compiler version 0.4.25 or more seasoned. Along these lines, if your compiler version is 0.4.3 or over this contract will go through a mistake.
2. Then smart grid contract is conveyed.
3. Next we have declared event "New Customer". Events are inheritable individuals from contracts. At the point when they are called, they cause the arguments to be put away.
4. Then we map the location of the new customer with contract address.
5. A constructor will be called while instating the contract. It will utilize msg.sender to mine the agreement and afterward convey the initial tokens for DSO.
6. A unique address is made for DSO after the agreement is conveyed.
7. Functions are utilized to perform explicit tasks. Like to enroll another customer or find a profile of effectively register customer in the system by conveying new agreement.
8. Emit is utilized to call the desired event.

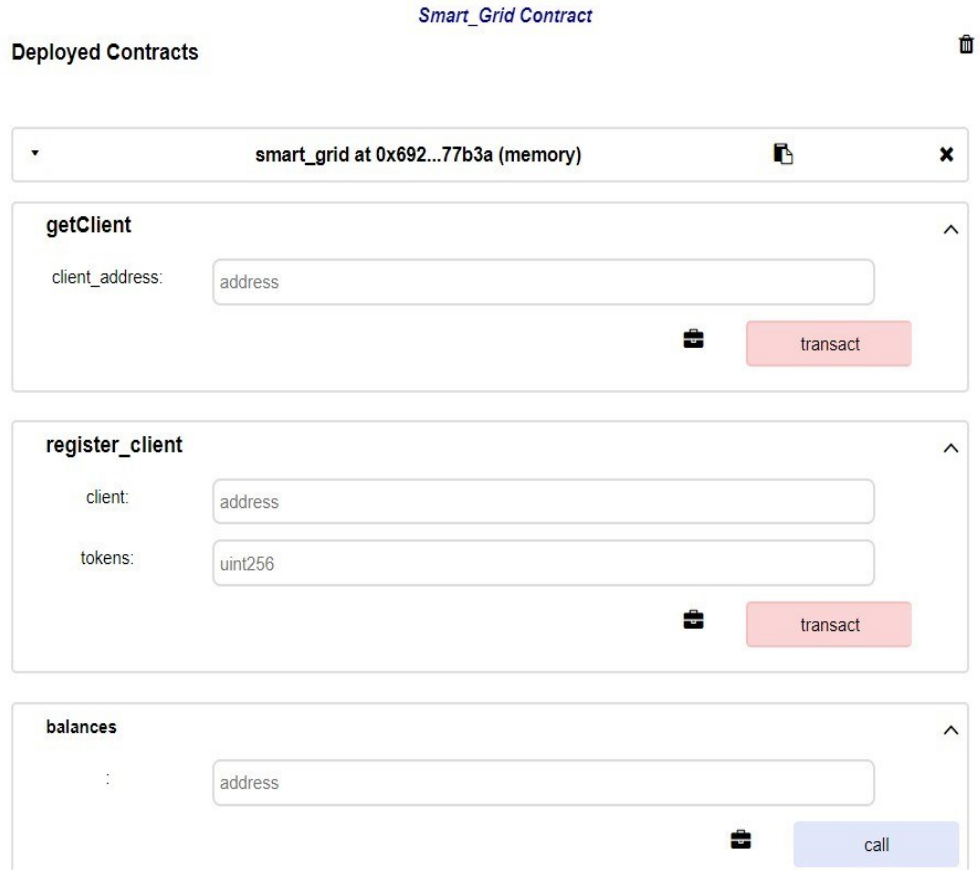

Figure 9. Virtual Smart Grid EVM representation for DSO

Figure 10 is the representation of the compiled version of the deployed agreement. After the execution of any function or new agreement, an exchange is made which is at last going to be put away in the blocks. Figure 10 additionally shows the unique address allocated for the DSO '0x692a70d2e424a56d2c6c27aa97d1a86395877b3a' after the smart grid contract is conveyed with 100 tokens sent as an exchange to DSO account. The insights concerning exchange cost and execution cost is also available in Figure 10.

Figure 10. Deployed smart grid contract

4.6 Client contract description

The subsequent agreement is 'Client' contract and its algorithm is given in Figure 11. Depending upon the client's sort, its agreement will either be a prosumer or a consumer.

The function incorporates 'payment' which is utilized for the payment of the electricity and 'get Balance' which used to see the current balance for the proprietors account.

```
Algorithm    Client Contract
mapping (address => uint256) balances
Init: address DSO
constructor (Tokens, new_client):
    Owner = new_client
    balanceOf[Owner] = InitialSupply

Event Transfer(Sender, Receiver, amount);
Function payment(Requester, Amount):
    if balanceOf[Requester] ¿ Amount then
        balanceOf[Requester] += Amount
        balanceOf[Owner] -= Amount
        return TRUE
    else
        return FALSE
    end

Event LowCredit(address, amount);
Function getBalance(Requester):
    return balanceOf[Requester]
```

Figure 11. Algorithm for Client Contract

Following is the description of the Client Contract deployed utilizing EVM:

1. Constructer is utilized for making client's address. DSO will mine the contract; however, owner is client.
2. Initial payment of tokens to the client's location, this will set the edge as composed above for an event of Notification for low credit.
3. Second event is the warning of the exchange for credit move.
4. We have a design for client type which can be a prosumer or a consumer depending on the client's sort.
5. And, for the utilization or creation of total electricity, there is a payment function work used to change over electricity units.
6. The function payment is utilized for the installment of the electricity used. The condition for the payment is to meet the total amount with client's balance to guarantee the payment and to refresh the new amount.
7. Emit is utilized to call the function for the notice for credit move.
8. The 'get Balance' function is utilized to see the current balance for proprietor's record.

Modifiers can be utilized for more explicit outcomes like utilizing safer wallets and keys as multi-signature exchanges according to require for additional outcomes.

Figure 12 addresses the perspective on the deployed client contract, build utilizing EVM and smart contract (additionally accessible in Appendix 2).

Figure 12. Virtual Smart Grid EVM representation for client

Also, Figure 13 shows the outcomes after the execution of the client contract. A unique address is assigned to the client which is additionally its electronic wallet. Each exchange produced using or to this location will be refreshed inside the blocks and will be affixed by the Ethereum's blockchain. The deployment gas cost was 322244 gas (exchange cost) and execution cost was 202696 gas.

Figure 13. Deployed client contract

4.7 Performance analysis

The smart contracts sent in Ethereum approach have the most extreme measure of gas limit 3000000. As examined over each transaction has a base. The transaction cost of the initial smart grid contract was 675,585 gas and the execution cost were $0.1439, as demonstrated in Table 1.

Table 1. Ethereum's usage of gas and cost analysis

Operation	Gas Used	Price in $
Smart Grid Contract	675,585	$0.1439
Execution Cost of Smart Grid	471,529	$0.1004
The client contract	322,244	$0.0686
Transaction for electricity usage	23,552	$0.0050
Get balance	36,015	$0.0076

For our case, the upper limit reaches of 3,000,000 gas was set and from Table 2, we can see that the normal gas cost per transaction is 30,000. The determined normal time for another block is 15 seconds approx., at that point we can have 100 transactions in 15 seconds (because of as far as possible), it implies we can accomplish maximum limit of 6 transaction each second.

Table 2. Number of transactions per gas consumed

Amount of transactions	Gas consumed in normal transaction
1	36015
2	72030
3	108,045
4	144,060
5	180,075
6	216,090
16	576,240
32	1,152,480
64	2,304,960
100	3,601,500

As from Table 2, clearly Ethereum's blockchain will actually want to deal with 6 transactions each second. Thus the restriction of the power wastage and furthermore the limit to scalability which is restricted because of number of transactions each second.

CHAPTER 5

DISCUSSION AND LIMITATION

The prominence quality of blockchain in energy area and smart grid space appears to be obvious as well as unavoidable. Today, the creation of non-conventional energy is need of great importance. The best element of blockchain-based smart grid is certainly P2P energy exchanging while at the same time keeping away from third parties and energy losses.

The blockchain and its utilization case in energy area is still at creating stage and not without defects. There are numerous viewpoints actually should have been redesigned and exhumed.

5.1 Ethereum implementation

In a situation where a small P2P exchanging market should be set up (housing society). The electrical grid can be carried out utilizing the design proposed in Figure 6. DSO may be liable for balancing the grid or delay tolerant information (smart contract algorithm introduced in Figure 8). The smart meters introduced at prosumer and shopper end will have smart contracts which will perform market functionalities. The market payment function will be performed utilizing Ethereum's implicit cryptographic money and addressed here as Tokens. Each Token will address 1kW of power and the smart contracts will be answerable for fundamental conversions. Each transaction performed will be approved utilizing smart meters introduced at prosumers end (local energy suppliers). The general throughput for Ethereum execution was determined to oblige 5000 houses quickly (using architecture in Figure 6). 15 minutes is least an ideal opportunity for every one of the transactions to be refreshed and added to the blockchain network for the users to approach of the updated information.

This sort of contextual analysis suits perfectly for housing society with predetermined number of houses to make their own micro grid, which will run by totally neutral and decentralized innovation convention intended to profit prosumers and consumers [35]. The kind of local P2P power exchanging foundation is the best answer for energy sector to deal with the expanding number of local energy suppliers. There can be motivating forces set for the advancement of non-conventional production as far as bi-directional energy stream (mining rewards, no assessments, and so on) for prosumers. The general effect of presenting decentralized blockchain-based smart grid equipped with smart meters and smart contracts as demonstrated in Figure 6, will essentially affect diminishing future energy costs and advancing solar based and wind energy to establish clean and environmental friendly energy market.

5.2 Limitations

Since clearly blockchain has altered the financial sector, there is significantly more potential to be investigated in the selection of blockchain-based smart grids. The appearance of blockchain in smart grid actually should respond to numerous inquiries before it can totally overwhelm the previous frameworks. The self-evident truth that the blockchain innovation needs to substantiate itself first that it can give framework to deal with huge measure of ongoing information while offering speed, versatility and security.

Each arising innovation faces same exploratory stages actually like blockchain is being tried in smart grid area nowadays. To discuss about practical implementation, there is still a great deal to be explored as the innovation is in its advancing stage. The most self-evident and major obstacle is by all accounts the adaptability issues bringing about set number of exchanges and leading to restricted throughput limit.

5.3 Future work

It appears to be too soon to choose which blockchain convention accepts the ideal ascribes and right consensus mechanisms to achieve a perfect framework architecture in energy market and smart grid areas. The main component in any financial sector is cost and by wiping third parties, blockchain has to bring to the table a massive expense saving technique.

Right now, blockchain procedures offers modest strategies for P2P energy exchanging and give an establishment to build up steady measures for local energy suppliers to offer bi-directional energy flow. This won't just diminish cost yet additionally elevate approaches to battle fossil fuel byproduct in energy area.

Blockchain-based smart grid demonstrates to extremely proficient in micro grids, yet face numerous difficulties with regards to large scale implementations. The main consideration is as yet the absence of adaptability, interoperability and conflicts in normalizations. With time and legitimate examination, every one of the experienced difficulties can be battled and a develop blockchain-based smart grid will actually want to change the energy sector.

CHAPTER 6

CONCLUSION

To conclude, distributed record innovation, despite having previously mentioned blemishes, gives a huge potential to change the commercial center of the energy area. In particular, blockchain has to bring to the table novel answers for energize environmentally non-conventional energy sources and local energy suppliers to assume an overwhelming part in making this world cleaner and better to place to live in, with advancing low-carbon energy creations.

The work in the thesis gives a detailed outline of blockchain and smart grid related ideas. Then, the execution of methodology with itemized framework architecture are carried out to break down the exhibition of a virtual smart grid equipped for conveying smart contracts for market installment and related functions. The proposed architecture was executed by utilizing Ethereum Fabric stages. Ethereum is the most usually utilized blockchain-based convention however with adaptability restrictions. The execution strategies give top to bottom investigation as diverse contextual analyses and their near examination for the change of the energy area.

Ethereum execution offers answers for make a local P2P energy exchanging foundation among the houses a general public, which can support its power creation and utilization. The houses will for the most part utilize non-conventional techniques to deliver power and doesn't need to depend on public framework or any third party except if in a situation of load shedding or deficiency of energy in a chilly, non-blustery day of winter (generally occurs in February). The throughput limit if there should arise an occurrence of Ethereum execution can undoubtedly be overseen inside a microgrid. However, a limit of a smart grid is the most fundamental factor in choosing the utilization of the innovation.

IOT and AI gadgets will consolidate, and a more controlled environment is required. There is much more actually needs to research and create to for all intents and commercial usage of blockchain innovation in energy sector.

CHAPTER 7

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CHAPTER 8

APPENDICES

Appendix 1 SMART GRID CONTRACT

```
pragma solidity ^0.4.25;
import "./client_contract.sol";

contract smart_grid{

    event NewCustomer(address indexed client, address client_contract); /* Notification for
new customer registration*/
    mapping (address => address ) contract_registered; /* Map address of the new customer
with contract address*/

    /* maps balance*/
    mapping (address => uint256) public balances;
    address dso;

    /* constructer */
    constructor(uint8 tokens) public {
      dso = msg.sender; /* DSO mines the contract */
      balances[msg.sender] = tokens; /* Gives coins to DSO */
    }

    /* Register a new client in the system by deploying new contract*/
    function register_client(address client, uint256 tokens )public returns (address
contract_address){
      require(contract_registered[client] == 0x0);
      address new_client = new client_contract(tokens, client); /*for deployment of a new
contract*/
      emit NewCustomer(client, new_client);
      contract_registered[client] = new_client; /* map the contarct address with the client*/
      return new_client;

    }

      /* To find the contract address of the client*/
      function getClient(address client_address) public returns (address client_contract){
      return contract_registered[client_address];
    }

}
```

Appendix 2 CLIENT_CONTRACT

```
pragma solidity ^0.4.25;

contract client_contract{

    int256 threshold; /*threshold for low credit notification*/
    event Lowcredit(address indexed client, uint256 _value); /* Notification for low credit*/
    event Transfer(address indexed _from, address indexed _to, uint256 _value);
/*notification for credit transfer*/

    address owner;

     /* constructer */
    constructor(uint256 tokens, address new_client) public {
      owner = new_client; /* DSO mines the contract but owner is client */
      balances[msg.sender] = tokens; /* Gives intital coins to Client */
    }

    struct user{
      uint8 client_type;  /* 0 for consumer & 1 for producer*/
      uint256 total_electricity; /* Usage or production of electricity*/
    }

    /* maps balance*/
    mapping (address => uint256) public balances;

    /* payment of the electricity used*/
    function payment(address receiver, uint amount) public returns(bool sufficient) {
            if (balances[msg.sender] < amount) return false;
            balances[msg.sender] -= amount;
            balances[receiver] += amount;
            emit Transfer(msg.sender, receiver, amount);
            return true;
      }

      /*get account balances*/
      function getBalance() public view returns(uint) {
            return balances[msg.sender];
      }
```