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Using Blockchain for Decentralization and Security Enhancement of Smartgrid

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Abstract

The smart grid concept entails integrating energy flow with information flow for the purpose of forming a robust cyber-physical system which would enable participants' access to energy transactions. Integration of renewable energy and green energy alternative energy sources to the existing power grid is a primary vision of the smart grid concept. Hence enabling an efficient system of smart energy flow which is unrestricted in scalability and customer participation. Sustainability and maximum efficiency are the goal of the smart grid. With the number of growing connections increasing exponentially, the backbone of the smart grid which is the existing grid is experiencing coordination issues due to its centralized orientation. Hence adopting a decentralized topology for managing the smart grid is a viable approach to optimal management of the smart grid. Blockchain technology stands out as a best solution to these foreseen challenges that the smart grid is bound to encounter with its increasing expansion and growth. This paper therefore renders an extensive and detailed analysis of potentially integrating the blockchain technology into the smart grid. The cyber security benefits of adopting blockchain technology for the smart grid implementation is also discussed.

Keywords: Smart Grid, Blockchain, Security, Decentralized, Renewable Energy,

1. Introduction

In recent times, there has been a substantial growth in the adoption and utilization of renewable energy sources. This is in an effort to curb the growing challenges of the traditional existing grid system. The reduction in toxic emissions, reduction in global warming, avoidance of long distant transmission, and reduced cost implication is some of the reasons and benefits of the shift towards green and renewable energy.[1] Wider adoption of renewable energy potentially promises higher efficiency, lower cost, and gross sustainability. with exponential increase of power and energy-based devices in the digital space, identification and classification of these grid associated devices which play a role in control, monitoring, or utilization of power has become of high importance. Hence framing the landscape of smart grid universal digital ledger is essential. Fig 1 illustrates the concept of a two-way power flow distribution network in relationship with energy based digital space.

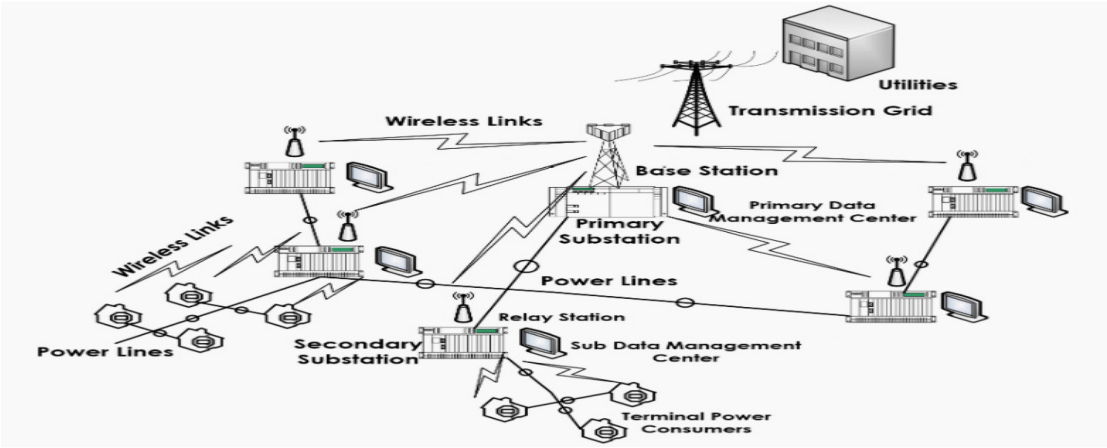

Figure 1

The smart grid, which has gained popularity recently, promises to enhance the merging of alternate renewable energy sources with the existing grid by the use adopting and utilization of improvements in technology. Hence interconnection of the source systems, smart and remote systems control and monitoring, communications and feedbacks between systems, and general implementations of advanced communication and control technologies are the key focus of the smart grid.

The smart grid generally aims at application of smart technology to manage, integrate, and deliver energy. This is achieved by advanced information and metadata sharing among component systems, hence making the integration of renewable and green energy a possibility.

The energy internet on the other hand differ in concept form the smart grid. The concept of the energy internet entails advanced technology in information communication applied to powers systems and the energy network. The main goal of this is applying innovative strategies to ensure connection and availability of energy to the target consumers. The smart grid however deals more with the integration of renewable energy sources to the traditional grid for the purpose of enhancing cost and sustainability.

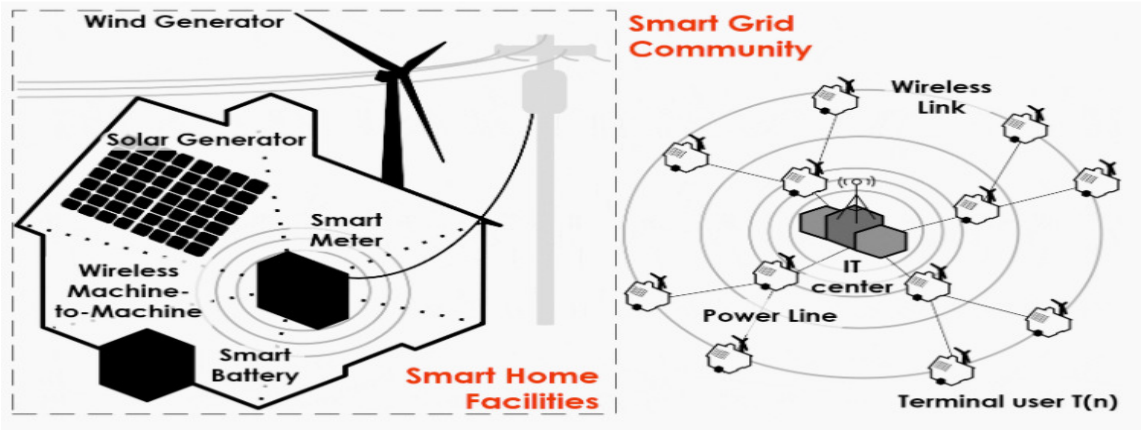

Figure 2

Both the energy internet and the smart grid works towards ensuring that the participants which are the producers and consumers are effectively networked and are active participants in the system through smart innovations and advancements in technology, hence, they are able to participate in decision making.[2]
Every terminal user(Tn) which is a component of the smart grid community set, can be a producer, consumer, or a prosumer. Hence the smart grid strives to provide a smart playground for all terminal users in the smart grid community. Fig2 illustrates the idea of a smart facility, as a component of the smart grid community.

with increase in connectivity integration and coordination of this increasing number of connected component systems and power components such as consumer networks and nodes, producers, vehicles and devices, cyber-physical systems, and miscellaneous component of the centralized grid is becoming increasingly problematic.[3] The management and sustainability of this growth increase requires proactive concepts and innovative solutions.

the idea of migrating the grid to decentralized framework is an enabling factor for sustainability of the smart grid.[4] Hence this will make for dynamic integration of components and will result in a more scalable and efficient system. Also, this will enhance the sustainability and reliability of the smart grid. Despite the foreseen benefits, there are also challenges that has to be considered. These include trust and security issues, privacy issues, and transmission delays. the block chain technology stands out as a viable solution to all the issue of making the smart grid decentralized.[5] The blockchain is a decentralized technology that also has the benefit of eliminating the security and trust issues with the conventional decentralized architecture. The blockchain technology entails elimination of a central authority of control and works by distributing control amongst participating components.

In the blockchain technology, transaction verification is a collective responsibility of the component systems. This eliminates the possibility of any security breach.

2.USE OF BLOCKCHAIN TO MONITOR, MEASURE, AND CONTROL

Currently, cyber-physical systems of the smart grid are basically built upon a centralized control and data acquisition system (SCADA). This has interconnections with elements such as RTUs-(remote terminal unit), MTUs-(master terminal units), PMUs-(phasor measurement units) other sensors and transducers in hierarchical structure. SCADA systems are generally used in the monitoring and controlling of energy grids. The SCADA systems which are integrated wholly with the existing internet network enables effective distribution measurement, monitoring, and control. sensors, IoT devices, other smart devices, PMUs, generally collect data and real time information on current status of which is shared with the MTUs, through the RTUs. Hence, MTUs act as centralized repositories as well as control units.

Securing the smart grid entails comprehensive knowledge of the various attack modes. Malicious damages and attacks can be perpetrated by malicious insiders or attackers with access to the central control. Hence variants of attack such as destructive data injections, disruption of availability, and other attack modes can be successfully initiated though devices, PMUs, and smart sensors.
This is one of the major advantages of the decentralized blockchain architectural framework. The attacker is not able to compromise the decentralized control as in the case of a central control. Therefore, no malicious attack data can be implemented or generated. There is more effective and transparent monitoring of the smart grid system

3.BLOCKCHAIN BACKGROUND

This section discusses Background details of blockchain. We introduce the concept of smart contracts and the consensus protocol, distributed ledger technology, and the categories of blockchain. The blockchain technology has gained global approval due to its undisputable success in the cryptocurrency industry and its recorded success in other applications.[6] As a distributed ledger, blockchain technology is potentially the ultimate standard. Due to its inherent characteristics all illustrated in the diagram below(Fig 3), the reliability of blockchains is absolute in archiving the listed benefits.

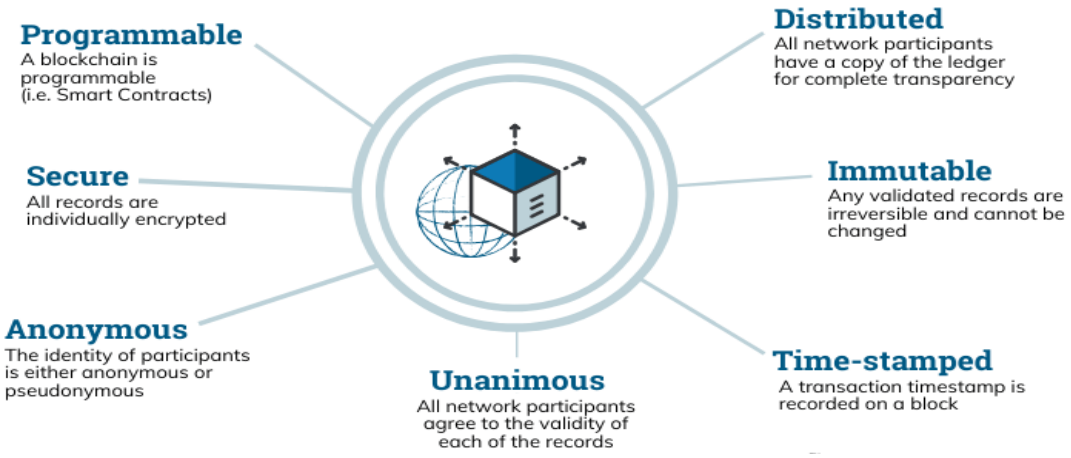

Figure 3

3.1 BLOCKCHAIN A DISTRIBUTED LEDGER

Blockchain is special kind of distributed ledger. However, the two terms Blockchain and distributed ledger are now being used to mean the same concept and is being used interchangeably.Distributed ledgers as the name implies, make use of independent distributed nodes or computers to record, manage, share, and ultimately synchronize the various transactions.[7] Hence instead of accessing data from centralized location as in a traditional ledger systems.

Blockchain and DLT are the enabling factor for the internet of value. This term "internet of value" refers to the transfer of value from peer-to-peer, without the need for central coordination

Distributed ledger technology (DLT) and blockchain is seen as having the potential to fundamentally modify the current state of the art in data processing with a goal of increased efficiency, resilience, and reliability.

in the blockchain system, data updates involve all participating nodes. This is usually done in an absolutely secure manner due to the validation process

3.2 SMART CONTRACT

the concept of smart contracts was first conceived by Nick Szabo(1992). A smart contract is simply a script that details the terms and agreement of the transaction. Hence this protocol defines the rules and is stored in the various blocks of the chain. The smart contract therefore records the transaction information, the conditions, and the events and all necessary metadata.

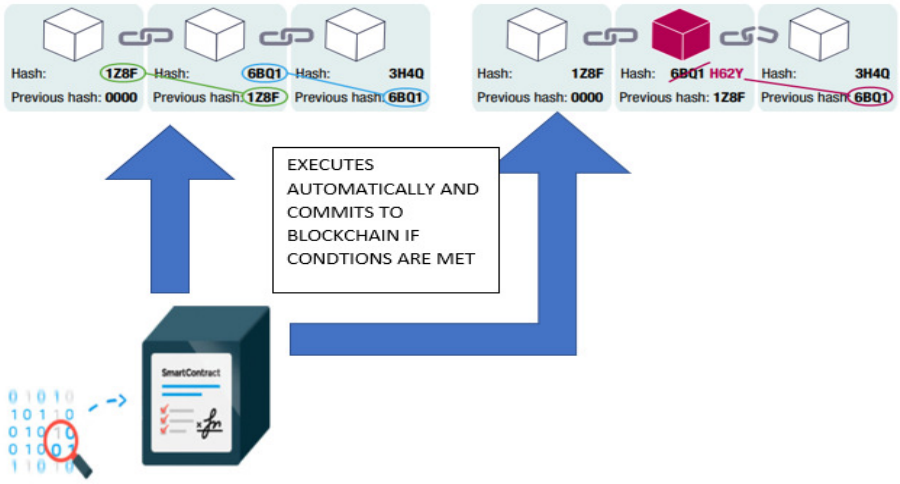

Figure 4

Smart contracts are self-executing upon the necessary conditions being met. Hence no central control is needed and trigger an execution. Figure 4 illustrates the concept of smart contract executing automatically and committing to the block chain. The smart contracts are the core intelligence behind the decentralized nature of the block chain technology.[8][9] And it is important to note that the functionality and principle of the blockchain system is dependent on the associated smart contract.

3.3 BLOCKCHAIN CATEGORIES

Permissioned vs Permission less: The modes on operation of the blockchain technology is dependent upon the solution which it seeks to achieve or the intended application. It may be necessary to restrict certain participants from the ability to create new blocks and to access certain existing information. Also, blockchain systems may be more efficient in terms of reduction in information propagation delays and processing delays with lesser participant nodes. Hence the concept of permission-less and permissioned refers to the level of permission granted to the blocks involved. In permissioned scenario,

specific member nodes have full access to participation in transaction processing while others have limited access.

Private vs. Public*:* the classification of blockchains as public or private is conceptually related to the permissioned and permission-less categorization. Public blockchains are refers to the arch type of blockchain which are wholly permission-less and decentralized. In the public blockchain the number of participants is usually high and are grossly characterized by anonymity. The opposite is the case for private blockchains since few nodes are preselected and assigned the necessary access and transaction rights. Hence the private blockchains may not be totally decentralized but may be designed to have the benefits of a fully decentralized system.

On-chain vs Off-chain*:* The term on chain is used to describe the transaction that visibly occur on the block chain and traditionally involving the nodes of the chain. Hence on chain transactions are authenticated and consummated on the chain by the participating nodes. On the contrary, if a transaction occurs off-chain, then the transaction has not been consummated y the nodes in the blockchain but rather occurred externally. In this scenario, the resources on the blockchain has not been utilized for this transaction. Off chain transactions has the advantage of being time effective and efficient since the time lags due to computational delays are eliminated. Also, off chain transactions have the advantage of being more private since data broadcasting Is limited.

Depending on the number or volume of transactions to be performed, the off-chain option has is usually a good choice for larger numbers of transactions.

3.4 CONSENSUS MECHANISMS

basically, the consensus mechanism or protocol ensures that each new block added to the Blockchain system is a one and only one version of the truth which is generally agreed upon by every nodes of the chain. Hence a consensus mechanism or algorithm finds a common agreement which is jointly agreed upon and is a suitable win for the entire blocks in the network.

When any network participating node creates any transaction, the created transaction is then broadcast to all nodes in the entire network. Each participant or node has to record the transaction and then add it into their version of history or truth which is the preexisting ledger or records. consensus mechanisms are usually fault tolerant. They are hence used to achieve agreement on any single data value or single state of the blockchain network, hence actuating the system of distributed processes in the blockchain consensus mechanisms makes sure that there is total trust in the blockchain network. This is because with this mechanism all validators confirm the validity of created blocks, hence authorizing it.

Proof of Work (PoW): This is the term which was used for the original blockchain consensus mechanism. “Proof of Work”, PoW, is essentially the original consensus mechanism or algorithm in the Blockchain. this protocol or algorithm functions to confirm all transactions and hence produce the blocks of the chain. With the PoW, miners of the blockchain compete with each other in the process to complete the blockchain transactions and creation of new blocks of the network.[10] Depending on the application, or the configuration of the system, these miners may get some reward or compensation. The proof of work can be seen as a puzzle which is usually computationally intensive. Although the PoW is usually difficult to solve, it is mostly always very easy to authenticate or verify. As soon as the PoW is solved, the solution, which is then attached to new block, is instantaneously broadcasted over the entire

network. Since the solution is attached to the new block, every other node can perform the verification task.

Proof of Stake (PoS): A variant of PoW is the proof of stake. This is an improvement of the proof off work concept which is mostly utilized in cryptocurrency block chain setups. In this set up, the the validation step serves as a replacement for mining. Hence the blocks are validated by the collective effort of the participating nodes.[11][12] Whereas for proof of work they are collectively mined by the participating nodes. Other proofing concepts used in the plockchain systems include Delegated Proof of Stake (DPoS), Leased Proof of Stake (LPoS), Proof of Activity (PoAc),
Proof of Burn (PoB).[13]

4 BLOCKCHAIN IN SMART GRID-THE DECENTRALIZATION PROCESS

Considering the benefits of adopting the blockchain technology for the smart grid, we discuss the potentials and expectations of adopting the blockchain technology into the smart grid. This study focuses more on the benefits of the use of the blockchain technology in the smart grid which may include privacy advantage, trust and security benefits and the general benefits of the decentralized nature of the blockchain technology

The main motivation for the introduction of the block chain concept to smart grid centered around security, ease of systems monitoring, fault tolerance, efficiency improvement, privacy of data, transparency, and trust.

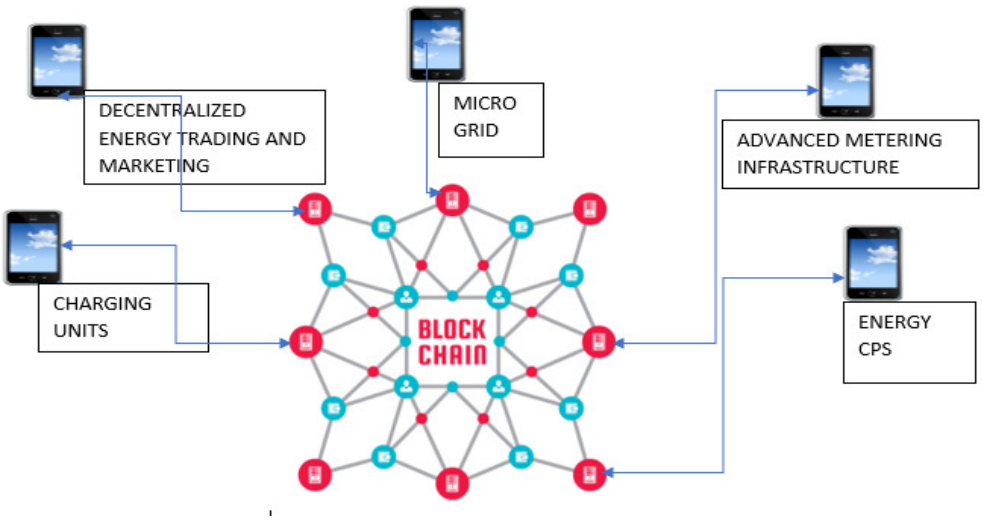

FIG. 5: Applications of Blockchain in Smart Grid Domain

Figure 5 above illustrates the aspects of the smart grid that will be grossly optimized with the adoption of the blockchain innovation.[14] These includes charging units for electric vehicles, decentralization of prosumer participation in energy trading, advanced metering infrastructure, cyber physical systems, and the microgrid. In this submission, we analyze the application of blockchain advanced metering infrastructure and in decentralized energy trading.

5.BLOCKCHAIN BASED ADVANCED METERING INFRASTRUCTURE

Advanced metering infrastructure (AMI) is all about integrating the smart metering system with the communications networks and data processing and managing systems so as to achieve a full duplex information flow between producers, energy utilities and power consumers and consumption terminals.[15] .

The AMI is a crucial factor in the smart grid initiative and with its automated architectural framework, real time energy data analysis is effectively facilitated, hence decision making by consumers, producers and prosumers is enabled in real time. Real time price adjustments and optimization is made possible in the smart grid with AMI.

With AMI, systems diagnostics, trouble shooting, and monitoring can be archived. The smart meters are hence assigned IP addresses and hence function as an independent node in the network with the ability to transmit and receive data in real time. [16]

The data transmission in AMI is archived via a WAN(wide area network) and data is stored in centralized data bases either on the cloud or any storage system. This centralized architecture has its potential risks such as loss of integrity by fraudulent modification, gross security, and privacy risks and also a single point of failure.

Again, this set-up is not adequately scalable as expansion may be hindered by the centralized architecture.

For AMI, blockchain technology through smart contracts, can be adopted to decentralize the AMI network.[17]

in the block chain system set up for AMI, the automated smart meters are connected to the blockchain, and these meters will transmit records or data which is used in the creation of new blocks. Timestamps are included for verifications. the consumers are billed by accessing the data that are recorded on the distributed ledger.

In this design, the blockchain is utilized to archive the desired secure and decentralized smart system. All nodes working independently and not depending on any central control, the decentralized system as a result is highly scalable and efficient. Also, records are adequately stored for reference purposes and are tamper proof.[18]Flexibility of the demand is implemented via the smart contract's intelligent algorithm. Hence as seen in the figure below(figure 6) the smart contract essentially tracks and balances the energy profiles of the participating prosumers. Hence adjustments are made by each participating prosumer based on the baselines as stipulated by the smart contracts. Therefore, blocks store values provided by the smart metering devices of the associated prosumer. The smart contract which are self-enforced, then performs the estimations and balancing hence evaluating the deviations and the necessary feedback is sent. Hence, the difference between the actual value of the energy and the expected value from the curve is used to evaluate the smart contract. Deviations are rebalanced by adjusting the energy

production with respect to demand. We see therefore that the smart contract performs the essential control function in a decentralized manner. Demand response actuation therefore occur in a decentralized manner, hence enabling real time flexibility in rates and pricing. Reward and penalty strategies are enforced upon prosumers depending on adherence or non-conformity to the smart contract.[19]

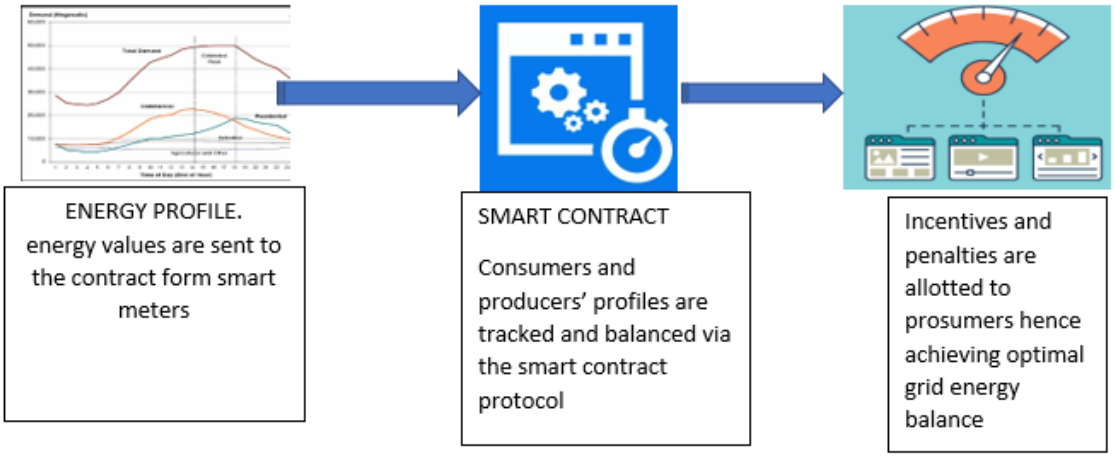

Figure 6

Privacy of participants is a major benefit of the block chain technology. Also guaranteed security is also a major advantage. In the figure, a permissioned model of block chain is utilized by use of supper node, smart contract servers, and edge device. In this set up, trust and correctness is guaranteed.[20]In this setup,the edge device assumes the roles of the participating node of the blockchain. The supper node on the other hand, performs control and authorization functions and grants permissions to other nodes in the network to participate in voting and consensus process.[21] Hence all functionality of the blockchain authorization process is archived and the traditional 51% authorization requirement is set in place for all validations. Then, the smart contract nodes serve as implementation nodes for the smart contract scripts. All modalities and protocols that govern the management of the edge devices and for resources allocation to consumers and users are contained in the smart contracts. The idea behind our strategic model is the utilization of a permissioned version of the blockchain technology. This is necessary to enhance privacy. The major components of our model include the edge nodes, supper nodes and the smart contract implementation node or server. The adoption of these threefold components implementation is necessary for accurate implementation of the permissions system and it guarantees both trustworthiness and correctness in the voting outcomes.

In fig 7 the major functions of the three layers is illustrated.[22][23]

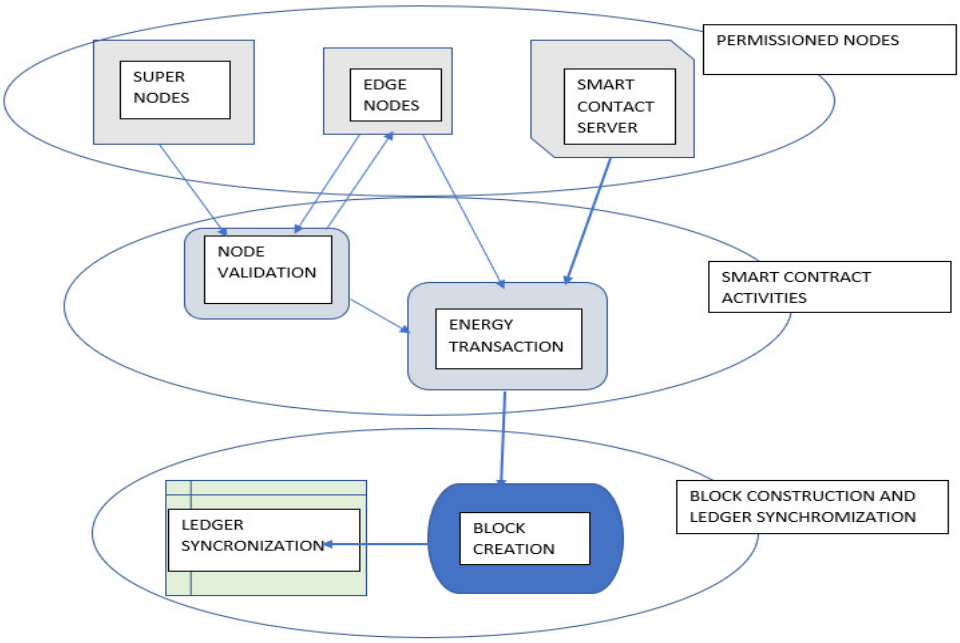

Figure 7

The supper nodes are responsible for validation of the edge nodes. The edge nodes on the other hand, are the active participants in the energy transactions and voting. The edge nodes are comparable with the voting nodes of the ordinary blockchain. Hence , the aim of permissioned block chain as implemented in this model is the authorization function as performed by the super nodes.

With respect to the smart grid implementation of this model, the edge nodes represent the edge infrastructural devices which mainly includes the smart meters and other measurement and monitoring equipment and sensors. Hence, the supper nodes are responsible for the validation of these edge nodes' identity and, hence authenticating them and granting them permission to participate in voting. This validation is in conformity with the 51% rule. Hence ensuring the trustworthiness of every participating edge node.[24][25]

By this scenario, through the adoption of the edge computing technology, the problem of computational limitations is avoided. Hence all edge computing requirements and problems such as power allocation to users are explicitly assigned to the edge nodes. All burdens of computation is shifted to the edge. Processing of service requests form users is a function which is therefore assigned to the edge nodes. Also, there is interaction between the smart contracts to the edge nodes. This link is also illustrated in the figure. The smart contract server is where the smart contracts are implemented.

Finally, upon consummation of energy transactions, new blocks are created, and the ledger is updated and kept in sync.

CONCLUSION

The smart grid enables enhanced interaction between consumers, producers, and brokers of power. Also, there is provision for new entrants into the system to get on board in a plug and play manner. Hence the

scalability of the smart grid is a factor which is dependent on its architectural framework due to its speed pf growth.

In this scenario, there is optimal utilization of produced power in an effective manner and sharing is enhanced since all surplus production is sold back to the grid. The advantage is that loss is minimized, and transmission delays are grossly eliminated hence making for a more efficient system. Also, sustainability of the system is greatly influenced due to the optimal balancing of supply and demand.

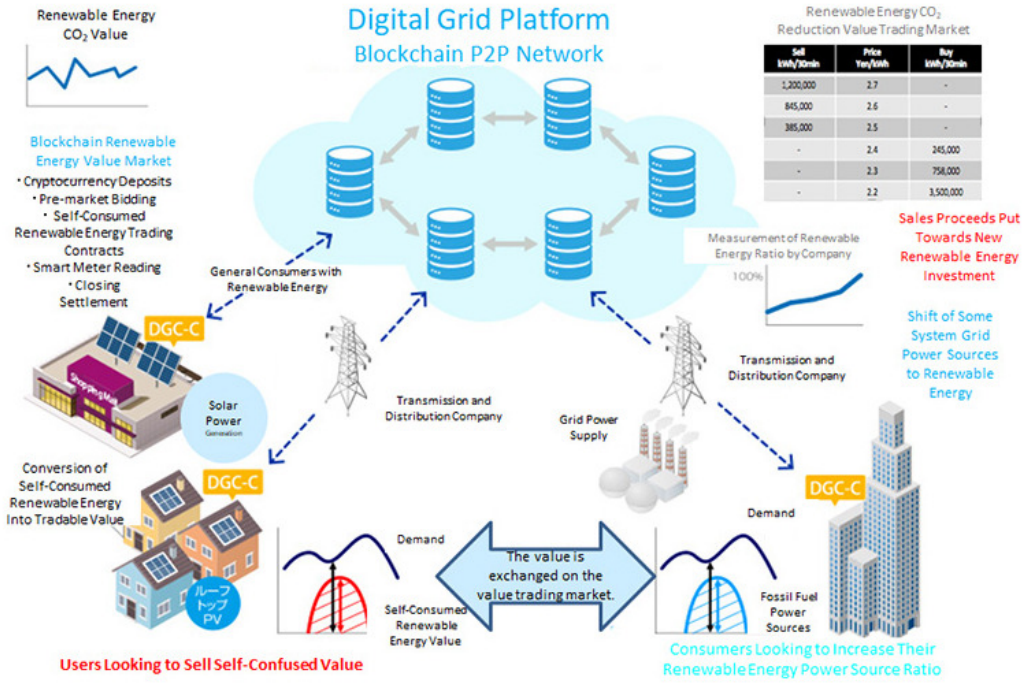

Figure 8

In this unified energy trading scenario, it is essential to adopt a system that will grossly enhance effective negotiation and bidding for available energy, and also enhance execution of contract amongst participants. The noninvolvementof a central coordinating intermediary in this energy trading is the major advantage of the smart grid block chain synergy. Hence trading of renewable energy among prosumers is greatly facilitated. Also, the challenges experienced with the involvement of intermediaries is eliminated.[26]

These is obvious cost benefits in elimination of middlemen control intermediaries in the energy supply chain. Due to added cost of operations and regulation, the per unit price of energy is higher with the involvement of intermediaries in the centralized framework.

The features of blockchain distinguishes it as the best technology for decentralizing the smart grid.

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