Security Aspects and Performance of Smart Grid with the Assistance of Blockchain Technology: An Intellectual Survey

[1] Dr. R. Latha, [2] N. Ganitha Aarthi

[1]*Professor, Department of Computer Science and Engineering, K. Ramakrishanan College of Engineering Tiruchirappalli , Mail_id: lathait64@gmail.com*

[2]*Research Scholar, Department of Information Technology, PRIST University Thanjavur. Mail_id: arthi.ganitha@gmail.com* .

Abstract: **-**Blockchain technology's cutting-edge capabilities have given rise to fascinating theories and subjects that developers and academics may use in their work. Blocks were a decentralized, distributed, open, immutable, and digital representation of transactions. Blockchain was created by chaining together blocks using encryption and hashing methods. The technology's goal is to treat data like money. Using this technology, it is possible to store in blocks the highly important data. The fastest-growing innovative technology used in many fields is called blockchain technology. It is well-liked because it may be used to a variety of fields, helping to contribute to data storage in the relevant fields linked via peer-to-peer networks. The technology offers a real-time updating facility feature that allows for the upgrading of the records. This study began looking into several Blockchain-related topics. It concentrated on blockchain applications that were already in use, analysed the proof of concept in various domains, and listed the benefits of the technology in various industries. The research aids in determining potential directions for future study in various fields.

Keywords*: Blockchain, block hash, ledger, key, cryptography, security, transaction, and Ethereum.*

1. Introduction

Online business and e-commerce are growing fast at this present time and most online payments rely on trusted third parties to process the transactions. The Financial Institution that serves as a third party has certain limitations and flaws like cost, time, and storage along with security issues. Irreversibility of the transaction is not avoided to address mediating disputes [1]. All these issues can be avoided if the transactions are happening by cash and in person. Since that is fast changing, for the payments to be successful and fraud-free there is a need for a new system without a central authority. The pandemic has accelerated the need for a new technology that is advanced at the same time secure [2, 3].

An electronic payment system of similar nature was proposed in 2008. It was proposed by a group of people or an unknown identifier namely Satoshi Nakamoto. The aim of the proposal by Satoshi and the team was to design an electronic system that allows parties to perform the transactions without involving third parties using cryptographic-proof techniques [4]. The innovation gave rise to a new technology known as Blockchain technology. The popularity, flexibility, functionality, and availability of this technology have made it more adaptable. The double spending problem and middleman in the payment are solved by this technology. It serves as a protocol for exchanging cryptocurrencies such as Bitcoins.

The very first cryptocurrency was Bitcoin to apply this for exchange. It solves a very familiar computer science problem "The Byzantine Generals Problem" which questions the consensus of distributed systems by providing a probabilistic approach. Many other crypto coins came into existence and gained popularity. Blockchain technology has become an attractive concept among the various researchers and developers as it is continuously growing set of records [5]. These records are grouped together into blocks, together with other information [6].

The blocks are chained together through the application of cryptography as shown in Figure 1. Every block contains hash of previous block, timestamp data and transactional data represented in the form of a Merkle tree as shown in Figure 2. A blockchain is called a decentralized ledger, as it saves all the transactions made in the peer-to-peer network [7]. Blockchain eliminates the role of intermediaries, thereby making it secure. Because of its features it is being used in a wide variety of applications in industries, financial sectors, health care systems and supply chain management systems.

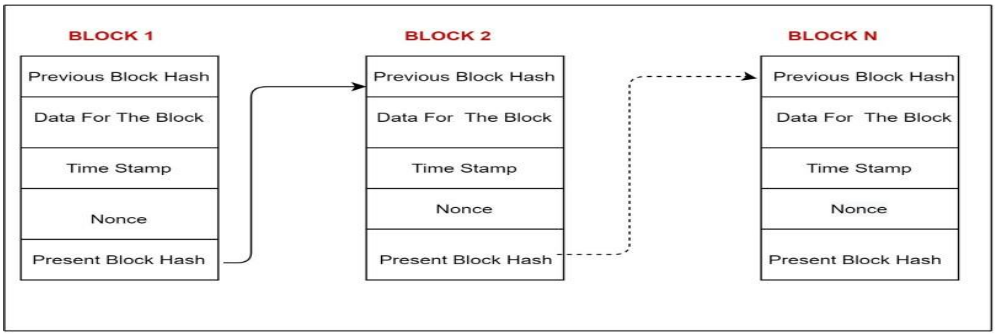

Figure 1: Representation of Blockchain

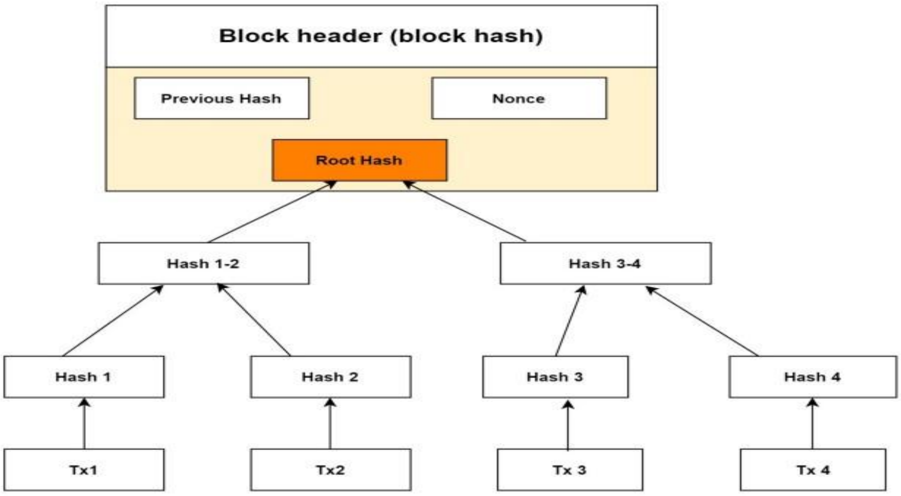

Figure 2: Merkle Tree of Transactions in a block

Blockchains apart from eliminating third parties also offer many other important features. Blockchain is a decentralized technology which enhances security by eliminating the centralized authority system. It is tampered proof, as the information is stored as cryptographic hash [8]. The block diagram for the following features is as shown in Figure 3 Some of the important features are:

Decentralized Ledger: Blockchain as a network, connects the users of the organization without third party interference. The transactions initiated in the network are shared to all the users in the peer-to-peer network. Every user in the network has the copy of the ledger in their node and sends that data to other nodes. Basically, it eliminates the central authority system like in banks and trusted intermediaries such as third-party service providers to exchange the value. It also reduces the resistance in the current transaction and creates a faster value exchange in real-time. Availability of the decentralized ledger across the network makes the system robust as there is no single point of failure occurring due to break down or collision. Hence, it increases the quality, reliability, and availability of service without any interruption.

Transparency in Blockchain: All the transactions are visible to everyone available in the network. It does not allow any unauthorized transactions to be embedded in to the blockchain. However, the participants in the network can select which information should be made publicly available during the initiation of the transaction [9]. Hence, every user in the network is provided with a digital signature also called the private key, i.e., proof of recognition for the node and the same is used to validate the transactions. However, the private key of the user is not to be disclosed to others. It is bundled with the public key to provide extra security to other users in the network.

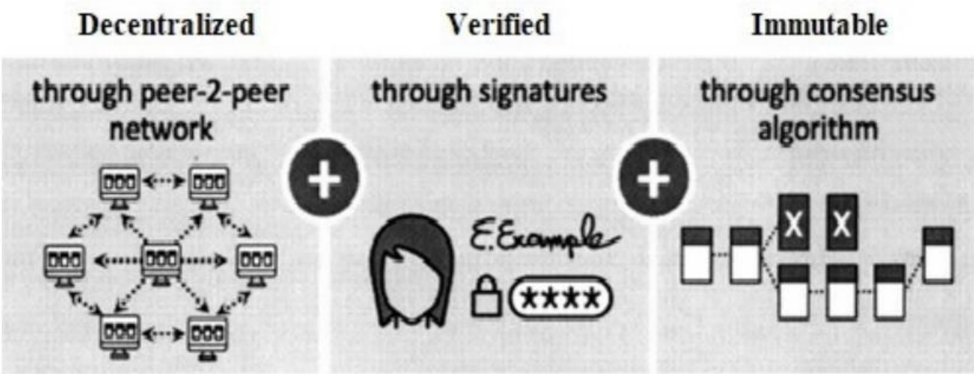

Figure 3: Properties of blockchain

Immutable Records: Blockchain use consensus algorithms to verify the transactions in a block and to embed them into the blockchain. If most of the participants in the network validate the group of transactions, then the transactions are included into the block to form a blockchain [10]. Suppose if any participant in the network tries to alter the ledger, he fails as it must be validated by a consensus. And every new block created is cryptographically linked to the previous block. Soon after new block is updated, all the nodes in the blockchain will get the copy of the updated ledger. Hence changing the block in the blockchain is impossible. So, this feature makes the records in blockchain immutable [11].Blockchain technology stands for having features like decentralized Network, distributed database and digital ledger that has the facility to update and store the data in an efficient way. The traditional approaches in the financial domain to more generic assets can be stored and connected using node-based peer-to-peer networks. So, it can be referred to as 3D technology. The data is secured and protected from tampering by using encryption techniques and cryptographic algorithms. Every transaction is timestamped and stored in a form of a block; later hashes are used to chain them. Both cryptography and hashing play a major role in Blockchain technology [12-14]. The Merkle tree concept is used to store the transaction details. The working of blockchain is illustrated in Figure 4.

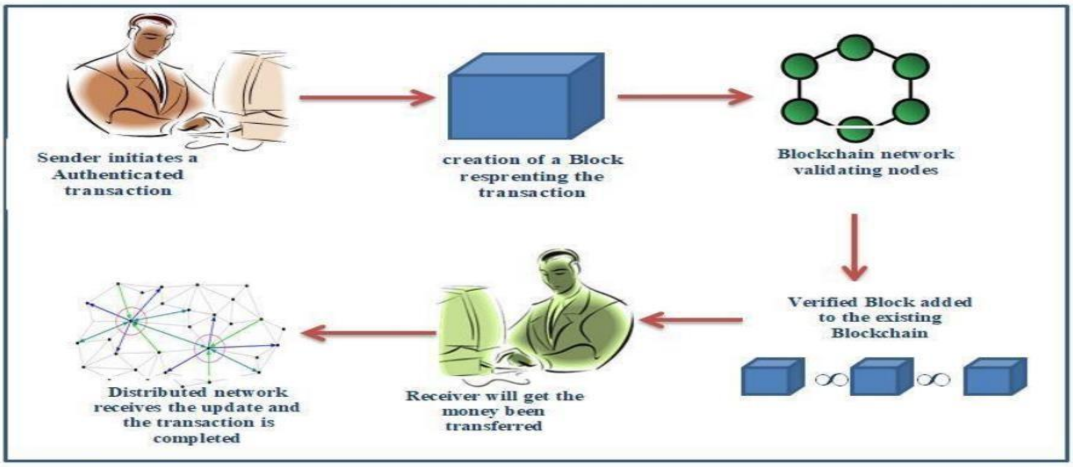

Figure 4. Working of Blockchain Technology

1. Architecture of Block chain

The blockchain architecture comprises of the following core components [15-21]:

Node: A peer node is a computer which equip with special software that maintains a blockchain. All nodes in the network can initiate transactions and exchange messages over a network.

Transaction: Transactions comprise of the smallest building entities participating in a blockchain system. Transactions are made up of nonce, gas price, gas limit, from address, to address, value and data. These transactions are responsible for altering the state of blockchain. They are grouped together and sent to every node to form a block. The processing and verification of these state changers are done independently in the peer-to-peer network. The format of a transaction consists of input, output, and a script signature. The input parameter holds a link to the previous node's output providing uninterrupted service whereas output field consists of data and the cost. The script signature is embedded into the input data structure. This signature is generated using the Elliptic Curve Digital Signature Algorithm. This script signature consists of the signature of the owner in the previous node and the current node's owner proving that the owner has designed the transaction to give his own input.

Block: Blocks are data structures whose prime purpose is to hold a group of transactions, which are bundle together by the miner after verification. Blocks structure mainly consists of block header which is the metadata and the transactions. Block header helps the miners to check the validness of the block. It consists of six fields namely – version, Previous Hash, Merkle root hash, Timestamp, Difficulty value and the nonce. Each of the above-mentioned metadata plays a vital role in the block's validation. Version holds the current version of the block structure; previous root hash refers the address of the previous node. Merkle root hash consists of the cryptographic hash of all the transactions embedded into the node; the time of creation is stored in timestamp; Difficulty value is the result of the mathematical puzzle's solution, number used only once is the random value embedded into the block.

Blockchain: It is chain of blocks, which are cryptographically linked to each other. Blockchain consists of various kinds of blocks – key chain blocks (nodes in current chain), lateral chain blocks (Nodes extending in the side chains) and the bereave blocks (these are left over nodes not known to processing). Lateral chain blocks and bereave blocks refer to the nodes in the key chain nodes.

Genesis Block: It is the first block in the blockchain, which define the initial configuration.

Network: It provides cooperation among all the nodes, so that they can execute and communicate with each other.

Miner: Miners collect transactions from mining pool send by various nodes in the network, solves the mathematical puzzle, verifies the cryptographic hash, thereby embedding them into a block. Miner can run on Ethereum node.

Mining: It is a process of a including a block by using proof-of-work, which will solve the complex mathematical puzzle.

Gas: It is the amount of the ether paid to run an EVM code on an EVM. Its price is set by the user. Miner will select the transaction based on gas price.

Call: Call to a function of an existing contract will execute the function code.

Consensus Mechanism: These act-like protocols ensuring synchronization of all the available nodes and to verify the common agreement among all nodes in the blockchain. To facilitate the distributed operation, and cooperation among the nodes. There may be faults occur in the system, which can be solved by using consensus. There are various kinds of consensus mechanisms working on various principles – Proof of Work (PoW), Proof of Stake (PoS), Delegated Proof of Stake (DPoS), Proof of Burn (PoB), Proof of Capacity (PoC), Proof of Elapsed Time (PoET), Consensus as a Service (CaaS) etc.

Hash function: Here the hash function accepts input as a combination of human readable characters comprising alphabets, numbers, special characters and can also accept various other files or media. The length of the output can vary between 32 – bit, 64 – bit, 128 – bit or 256 – bit, but all the generated outputs are of fixed bit length. This fixed length output can be generated depending on the encoding functions used. This is called hash code of that input sequence. There are many types of cryptographic functions available like Cyclic redundancy checks, Checksums, Universal hash function families, non-cryptographic hash functions, Keyed cryptographic hash functions, Unkeyed cryptographic hash functions. Out of which blockchain makes use of SHA-256 algorithm which belongs to Unkeyed cryptographic hash functions. This algorithm operates as a one-way function, producing unique fixed length outputs as shown in figure 2.4. The working of SHA – 256 algorithm differs from other encryption algorithms which uses keys to encrypt and decrypt text, in a way that it generates a message digest which is one – way. The message digest generated here cannot be decrypted by any of the decryption algorithms as it is only one – way code. As a result of this hashing any modification done to any of the blocks will generate a new hash code, breaking the chain. Hence to embed this new node into the chain all the node's hash values have to be altered making it almost impossible for a miner. This property of blockchain makes the data immutable.

Ethereum Virtual Machine (EVM): This is a computing machine, which provides an environment for the execution of EVM byte code. It has a limitation on number of computational steps, which is defined as gas.

Ethereum Network: It is a peer-to-peer network, which contains Ethereum nodes.

Ether: It is crypto currency used in the Ethereum platform to incentivize computation. Ethereum is popular and mature platform for developing smart contract.

Smart contract: It codifies the rules and regulations of organizations.

Contract Account: It is controlled by its contract code and can be initiated by an EOA using a call or function.

Go-Ethereum (Geth): It provides a command line interface to run an Ethereum node implementation in GO language. Geth functions can be accesses over a HTTP using JSON-RPC protocol.

State: Which is used to map between addresses and account states.

Account State: It consists of a nonce, balance, and storage root and hash value. Nonce represents the number of transactions sent from the account. Whereas the balance is the ether value owned by an account and storage root is the 256-bit hash of the root node in the hash tree. The EVM code is executed when the account receives a message call.

Externally Owned Account: It is controlled by an external actor with the private key. But it does not have any associated EVM code. EOA can issue a transaction to transfer ether or to initiate a contract account.

Solidity: It is a programming language used for writing the smart contract. The syntax is similar to the JavaScript, and it is developed to target the Ethereum platform. The miner, groups the transactions together in the form of blocks in the blockchain. The blockchain consist of data structure, which will link the block of transactions together, and these blocks will be stored as a database. Every block connected to the previous block in the form of chain starting from the genesis block, the current block stores the hash of the previous block. The block in the blockchain is indicated by the hash of the block header, Hash is generated using SHA-256. The figure 2.1 shows how the blocks are linked by using the previous block hash in the current block header.

The Structure of a Block: The block header consist of one parameter is hash of the previous block, and also hash of the Merkle root of the transactions to, time stamp of the block, difficulty target of the block, and nonce (which is a solution obtained by solving POW algorithm). The block structure is shown in the figure 2.1, we will discuss detailed in the following section.

Verification of Transaction: Immediately after user initiates a transaction, the transaction is broadcast to the neighbouring nodes of Ethereumblockchain until it is received by everyone in the network. According to the protocol, every node requires validating the originality of a transaction prior to the forwarding to the neighbouring nodes, and making sure that the transaction forwarded is a valid one and added in a block (at the same time fake transaction is discarded by node).

Mining and Proof-of-Work: Mining is the process of adding blocks to the blockchain; block uses a proof-of-work concept, where miner participating in the Ethereum network uses software and hardware to solve the mathematical puzzle. The function of a Mining is to oversee to manage the ethers in the Ethereum and it takes care the security of the transactions against attacker, known as double spending. The miner who solved the mathematical puzzle to include the block in the blockchain rewarded with Ether (1 Ether = 546.85 USD) and miner will gain the transaction fee of transactions added in the block. The entire mining process is incentivizing miner to perform mining and validate the transactions.

Proof – Of - Work Algorithm: Mining process use the POW algorithm, which consist of performing a SHA-256 to the block header continuously, randomly changing the parameter (nonce) till the final hash reach the difficulty target. SHA is a one-way hash function, so that the resulting block header hash cannot measure priory, as every hash is independent from each other. Hence, the final answer needs "brute force" answer, i.e minor search and test for a nonce continuously. Generally, nonce is incremented by one for each answer. SHA-256 algorithm is generating a fixed length of output for the variable length of input. The output of hash algorithm is same for the input always, so it can be easily measured and verified by anyone using the hash algorithm. Whereas it is impossible to determine the input for a given output. SHA-256, output is always 256-bit long. The below example shows the randomness of the algorithm. During the mining the integer appended is a nonce and is used to change the final hash values appended to it.

2. Working of Blockchain Technology

Initiation of New Transaction User on a blockchain can access to the network, which saves the data from all the transactions included in the block and are linked as a chain. Later, the transaction is broad cast over the network for validation by every node in the network [22, 23]. For instance, in a blockchain transaction will give the information of how the crypto currency is moved from one account to other, it record the sender account, receiver account and value [24]. Crypto currency is moved from one account to other, it record the sender account, receiver account and value. Generally, during the network operation very large number of transactions are broadcasted simultaneously over a network [25, 26].

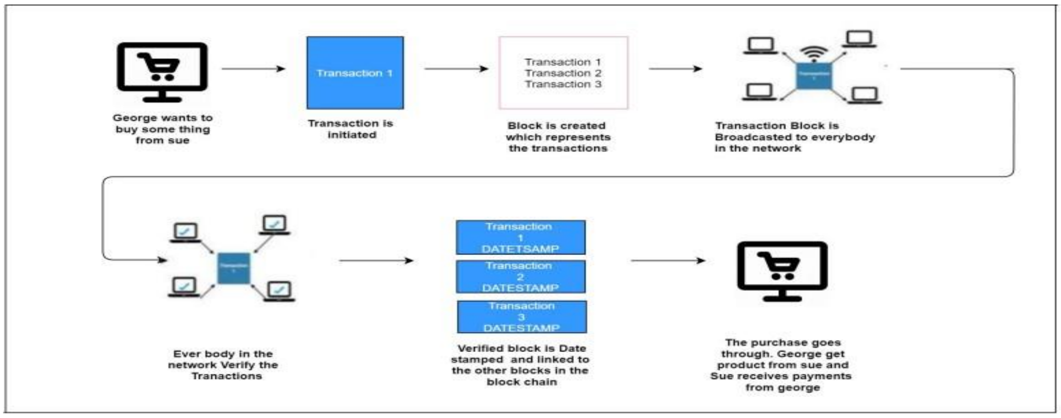

Figure 4. Blockchain Technology Process

Creation of New Block The miner is accountable to validate every transaction and saved in the global ledger. At the starting stage before actual mining starts, each miner in the blockchain is independently validate each transaction, by following the blockchain protocol, node identity verification using digital signature and any conflicts with the existing transactions. After a validation of transaction is completed, miner starts arranging this transaction in a candidate block. The candidate block is created by each miner, but these blocks are not part of the blockchain. This process continue until the block size reaches a maximum limit, which is priory defined as part of the blockchain protocol. Immediately after the candidate block is ready for mining process, then miner record the timestamp in the block header, add the previous block hash into the candidate block. By using time stamp, blockchain will link the data linearly to avoid any repetition by using the previous block hash value, which provides the data secure from alteration by the attacker [27].

3. Types of Blockchain

Blockchain categories are public, private, consortium [28].

Public: In a public blockchain every participant in the network can read, send transaction, and perform the consensus process to determine the block, which can be added to the blockchain network. The user having a computer and internet can participate and perform the consensus. Public blockchain allows the all the users to participate in the process. It is suitable for a fully decentralized network. It is slow and more energy consume in the form of power.

Private: It is completely private network, read permission is open but write permissions are maintained centrally by one organization. As only one organization can write and verify the transactions. So, its efficiency is more than the public blockchain. And is also very fast processing. But it does not offer same decentralized security as public blockchain.

Consortium: The consortium blockchain is controlled by the pre - selected nodes to control the consensus mechanism. Instead of all nodes allowed to participate in the blockchain or few nodes allowed for consensus process in private blockchain, only few nodes, which are control the consensus process. It is considered as partially decentralized network. So, it is more suitable application for business collaborations. For example, it can be used for business collaboration contains five organizations, each one maintains a separate node. Read permissions are public or restricted to few nodes. Suppose one organization does not want to participate in the consensus mechanism, but still it is part of the business partner, then it is allowed for read permissions.

4. Block chain in Smart Grid

This section primarily discusses the possible benefits of using blockchain in smart grids. As a result, we start by thoroughly describing the future smart grid system [29]. To demonstrate how these will eventually encourage the use of blockchain in smart grid, we now go through the characteristics of blockchain as well as the security, privacy, and trust goals that can be met by blockchain. It modernises the outdated traditional grid by utilising digital computing and communication technologies to create a more precise, effective, and intelligent energy access and delivery network. The aggressive climate change and the need for sustainable energy sources have caused these transformations and modernizations. The goal of these modernization and transformation efforts is to reshape the energy landscape by boosting the use of distributed and renewable energy sources while reducing reliance on fossil fuel-based power. By deploying independent dispersed producers of renewable energy, the smart grid paradigm puts producers and consumers closer together than the traditional legacy system, which feeds customers through long-distance transmission lines.

The smart grid, which is primarily supported by DERs like solar, wind, and fuel cells, is increasingly incorporating the microgrid, a grid paradigm [30]. A localised network of DERs, battery storage systems, electric vehicles (EVs), smart appliances, and loads is referred to as a microgrid, and the generating units are often situated near to the loads. The Smart Grid's solutions are shown in Table 1.

Table 1. Smart Grid Solutions

Work	Focused Application	Major Contribution	Technical Approach
[31]	Transactive energy applications	Facilitating secure and fast energy exchange of DERs by means of blockchain-based AMI	Public blockchain and smart contract
[32]	Decentralized demand response programs management	A blockchain-enabled distributed edger for storing smart meter data (considered as energy transactions) to utilize in making a balance between energy demand and production	Public blockchain, Smart contract, Ethereum platform, and Proof of Stake (PoS)
[33]	Traceable and transparent energy usage	A permissioned blockchain to ensure privacy and energy security (traceable and transparent energy usage) in smart grid	Group signature, covert channel authorization technique, smart contract, Permissioned blockchain, edge computing, pseudo names, and voting-based consensus
[34]	Energy demand and supply information	A blockchain-based privacy-preserving energy scheduling model for energy service company	Lagrange relaxation algorithm, smart contract, and PoS consensus
[35]	Peer-to-peer energy trading	A consortium-based energy blockchain	Credit-based payment system, consortium blockchain, and Stackelberg game theory
[36]	Decentralized energy trading and pricing	A proof-of-concept deployment of blockchain-enabled secure energy transactions and privacy-preserving techniques to negotiate en	Multi-signature, Anonymous Messaging Streams, PoW, Elliptic Curve Digital Signature Algorithm (ECDSA)
[37]	Smart grid power trading	A consortium blockchain-assisted efficient, flexible, and secure energy trading	PoS, consortium blockchain, smart contract
[38]	Energy trading in Vehicle to Grid (V2G) setup	A blockchain-enabled hierarchical authentication mechanism for privacy-preserving energy transactions in V2G networks and rewarding to EVs	Elliptic curve cryptography (ECC), PBFT consensus mechanism
[39]	Crowdsourced energy system, P2P energy trading, and energy market	A blockchain-assisted operational model of crowdsourced energy system and energy trading	Smart contract, Redundant Byzantine Fault Tolerance (RBFT), permissioned blockchain
[40]	Interconnected cyber physical systems (CPS)	A blockchain-based architecture for industrial control system named ICS-BlockOpS to ensure operational data immutability, integrity, and redundancy	Smart contract and voting-based consensus
[41]	Monitoring on smart grid	Applying blockchain to smart grid monitoring between electricity companies and consumers for data transparency	Smart contract and sidechain
[42]	Industrial CPS	A blockchain-oriented partially decentralized architecture for more secure and reliable industrial CPS system and solving current limitations of cloud-based system.	Private blockchain, access control lists (ACL), PoW

[43]	Electric vehicles (EVs) charging services in smart community	A blockchain-based solution coupled with contract theory to develop a secure electric vehicle charging framework including optimal scheduling algorithm and novel energy allocation in IoE	Contract theory, permissioned blockchain, reputation based DBFT consensus, and smart contract
[44]	ESUs charging coordination in smart grid	A blockchain-based decentralized, transparent, and privacy-preserving charging coordination mechanism for ESUs such as batteries and EVs	Smart contract, Knapsack algorithm, partially blinded signatures
[45]	EVs and their charging pile management in IoE	A decentralized security model named LNSC based on blockchain to enhance the security of transactions between electric v	Lightning network, smart contract, elliptic curve cryptography
[46]	EVs charging management	A blockchain-assisted automated and privacy-preserving protocol to search an optimum charging station relied on energy pricing as well as distance to the EVs	Smart contract
[47]	Microgrid optimization and control	A decentralized microgrid operational architecture builds on blockchain and alternating direction method of multipliers (ADMM) to address the monopoly price manipulation and privacy leakage problems by microgrid aggregators or operators	Smart contract and ADMM
[48]	Voltage control in microgrid	A blockchain-based proportional-fairness control framework to provide incentives to the distributed energy resources (DERs) for their contributions in voltage regulation in mic	Smart contract, PoW
[49]	Grid operation services for TES	A blockchain-based distributed voltage regulation algorithm fo	Smart contract
[50]	Grid operation services for TES	A blockchain-based distributed voltage regulation algorithm for tran	Smart contract
[51]	lectricity transactions in microgrid	A blockchain and continuous double auction (CDA) based decentralized microgrid electricity transactions mode to offer independent transactions between distributed generations (DG) and	CDA, multi-signature, PoS
[52]	Resilient networked microgrids	A decentralized transactivemicrogrid model	Smart contract and contract theory

A specific virtual or physical microgrid can trade local energy thanks to the creation of neighbourhood-wide marketplaces using blockchainmicrogrid. By using waste heat, reducing energy wasted through transmission lines, managing power supply and demand, and enhancing system resilience to adverse weather, microgrids can aid in the deployment of additional zero-emission energy sources. Due to reverse power flows from distributed generation units, local oscillations, transient microgrid modes, severe frequency deviations in islanded mode operation, as well as economic and supply-demand uncertainties, stability, reliability, and protection are the main problems with microgrids. The community can maintain system transactions in a consensus-based manner thanks to the integration of blockchain into the smart grid. Smart contracts are used to carry out transactions. The blockchain stores transaction history, which is duplicated across all full nodes.

5. Conclusion

Blockchain technology is defined by properties including a distributed database, decentralised network, and digital ledger with the ability to efficiently update and store data. Peer-to-peer networks built on nodes can store and link more general assets utilising the conventional methods used in the financial sector. So, it is also known as 3D technology. By utilising encryption methods and cryptographic algorithms, the data is safeguarded and kept safe from manipulation. Each transaction is timestamped, saved as a block, and chained together using hashes. Hashing and cryptography both play a significant part in Blockchain technology.

Reference

[1] Javaid, M., Haleem, A., Singh, R. P., Khan, S., &Suman, R. (2021). Blockchain technology applications for Industry 4.0: A literature-based review. *Blockchain: Research and Applications*, 100027.

[2] Ali, O., Jaradat, A., Kulakli, A., &Abuhalimeh, A. (2021). A comparative study: Blockchain technology utilization benefits, challenges, and functionalities. *IEEE Access*, *9*, 12730-12749.

[3] Balcerzak, A. P., Nica, E., Rogalska, E., Poliak, M., Klieštik, T., &Sabie, O. M. (2022). Blockchain technology and smart contracts in decentralized governance systems. *Administrative Sciences*, *12*(3), 96.

[4] Alam, A. (2022). Platform Utilising Blockchain Technology for eLearning and Online Education for Open Sharing of Academic Proficiency and Progress Records. In *Smart Data Intelligence* (pp. 307-320). Springer, Singapore.

[5] De Filippi, P., Mannan, M., &Reijers, W. (2022). The alegality of blockchain technology. *Policy and Society*, *41*(3), 358-372.

[6] Bhutta, M. N. M., Khwaja, A. A., Nadeem, A., Ahmad, H. F., Khan, M. K., Hanif, M. A., ... & Cao, Y. (2021). A survey on blockchain technology: evolution, architecture, and security. *IEEE Access*, *9*, 61048-61073.

[7] Centobelli, P., Cerchione, R., Del Vecchio, P., Oropallo, E., &Secundo, G. (2022). Blockchain technology for bridging trust, traceability, and transparency in circular supply chain. *Information & Management*, *59*(7), 103508.

[8] Upadhyay, A., Mukhuty, S., Kumar, V., &Kazancoglu, Y. (2021). Blockchain technology and the circular economy: Implications for sustainability and social responsibility. *Journal of Cleaner Production*, *293*, 126130.

[9] Idrees, S. M., Nowostawski, M., Jameel, R., &Mourya, A. K. (2021). Security aspects of blockchain technology intended for industrial applications. *Electronics*, *10*(8), 951.

[10] Johar, S., Ahmad, N., Asher, W., Cruickshank, H., &Durrani, A. (2021). Research and applied perspective to blockchain technology: A comprehensive survey. *Applied Sciences*, *11*(14), 6252.

[11] Da Xu, L., Lu, Y., & Li, L. (2021). Embedding blockchain technology into IoT for security: A survey. *IEEE Internet of Things Journal*, *8*(13), 10452-10473.

[12] Lei, N., Masanet, E., &Koomey, J. (2021). Best practices for analyzing the direct energy use of blockchain technology systems: Review and policy recommendations. *Energy Policy*, *156*, 112422.

[13] Javed, A. R., Hassan, M. A., Shahzad, F., Ahmed, W., Singh, S., Baker, T., &Gadekallu, T. R. (2022). Integration of blockchain technology and federated learning in vehicular (iot) networks: A comprehensive survey. *Sensors*, *22*(12), 4394.

[14] Bayramova, A., Edwards, D. J., & Roberts, C. (2021). The role of blockchain technology in augmenting supply chain resilience to cybercrime. *Buildings*, *11*(7), 283.

[15] Hasankhani, A., Hakimi, S. M., Bisheh-Niasar, M., Shafie-khah, M., &Asadolahi, H. (2021). Blockchain technology in the future smart grids: A comprehensive review and frameworks. *International Journal of Electrical Power & Energy Systems*, *129*, 106811.

[16] Khanfar, A. A., Iranmanesh, M., Ghobakhloo, M., Senali, M. G., &Fathi, M. (2021). Applications of blockchain technology in sustainable manufacturing and supply chain management: A systematic review. *Sustainability*, *13*(14), 7870.

[17] Rejeb, A., Rejeb, K., Simske, S., &Treiblmaier, H. (2021). Blockchain technologies in logistics and supply chain management: a bibliometric review. *Logistics*, *5*(4), 72.

[18] Abd-Alrazaq, A. A., Alajlani, M., Alhuwail, D., Erbad, A., Giannicchi, A., Shah, Z., ... &Househ, M. (2021). Blockchain technologies to mitigate COVID-19 challenges: A scoping review. *Computer methods and programs in biomedicine update*, *1*, 100001.

[19] Park, A., & Li, H. (2021). The effect of blockchain technology on supply chain sustainability performances. *Sustainability*, *13*(4), 1726.

[20] Liu, J., Zhang, H., & Zhen, L. (2021). Blockchain technology in maritime supply chains: Applications, architecture and challenges. *International Journal of Production Research*, 1-17.

[21] Latif, S., Idrees, Z., e Huma, Z., & Ahmad, J. (2021). Blockchain technology for the industrial Internet of Things: A comprehensive survey on security challenges, architectures, applications, and future research directions. *Transactions on Emerging Telecommunications Technologies*, *32*(11), e4337.

[22] Niknejad, N., Ismail, W., Bahari, M., Hendradi, R., &Salleh, A. Z. (2021). Mapping the research trends on blockchain technology in food and agriculture industry: A bibliometric analysis. *Environmental Technology & Innovation*, *21*, 101272.

[23] Raja Santhi, A., &Muthuswamy, P. (2022). Influence of blockchain technology in manufacturing supply chain and logistics. *Logistics*, *6*(1), 15.

[24] Rejeb, A., Rejeb, K., Simske, S. J., & Keogh, J. G. (2022). Blockchain technology in the smart city: A bibliometric review. *Quality & Quantity*, *56*(5), 2875-2906.

[25] Stallone, V., Wetzels, M., &Klaas, M. (2021). Applications of Blockchain Technology in marketing systematic review of marketing technology companies. *Blockchain: Research and Applications*, 100023.

[26] Chattu, V. K. (2021). A review of artificial intelligence, big data, and blockchain technology applications in medicine and global health. *Big Data and Cognitive Computing*, *5*(3), 41.

[27] Teisserenc, B., &Sepasgozar, S. (2021). Adoption of blockchain technology through digital twins in the construction industry 4.0: A pestels approach. *Buildings*, *11*(12), 670.

[28] da Silva, C. F., & Moro, S. (2021). Blockchain technology as an enabler of consumer trust: A text mining literature analysis. *Telematics and Informatics*, *60*, 101593.

[29] Nabipour, M., &Ülkü, M. A. (2021). On deploying blockchain technologies in supply chain strategies and the COVID-19 pandemic: a systematic literature review and research outlook. *Sustainability*, *13*(19), 10566.

[30] Haleem, A., Javaid, M., Singh, R. P., Suman, R., &Rab, S. (2021). Blockchain technology applications in healthcare: An overview. *International Journal of Intelligent Networks*, *2*, 130-139.

[31] M. Mylrea and S. N. G. Gourisetti, “Blockchain for smart grid resilience: Exchanging distributed energy at speed, scale and security,” in 2017 Resilience Week (RWS). IEEE, 2017, pp. 18–23.

[32] C. Pop, T. Cioara, M. Antal, I. Anghel, I. Salomie, and M. Bertoncini, “Blockchain based decentralized management of demand response programs in smart energy grids,” Sensors, vol. 18, no. 1, p. 162, 2018.

[33] K. Gai, Y. Wu, L. Zhu, L. Xu, and Y. Zhang, “Permissioned blockchain and edge computing empowered privacy-preserving smart grid networks,” IEEE Internet of Things Journal, vol. 6, no. 5, pp. 7992–8004, 2019.

[34] S. Tan, X. Wang, and C. Jiang, “Privacy-preserving energy scheduling for escos based on energy blockchain network,” Energies, vol. 12, no. 8, p. 1530, 2019.

[35] Z. Li, J. Kang, R. Yu, D. Ye, Q. Deng, and Y. Zhang, “Consortium blockchain for secure energy trading in industrial internet of things,” IEEE Transactions on Industrial Informatics, vol. 14, no. 8, pp. 3690– 3700, 2017.

[36] N. Z. Aitzhan and D. Svetinovic, “Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams,” IEEE Transactions on Dependable and Secure Computing, vol. 15, no. 5, pp. 840–852, 2016.

[37] D. Zheng, K. Deng, Y. Zhang, J. Zhao, X. Zheng, and X. Ma, "Smart grid power trading based on consortium blockchain in internet of things," in International Conference on Algorithms and Architectures for Parallel Processing. Springer, 2018, pp. 453–459.

[38] S. Garg, K. Kaur, G. Kaddoum, F. Gagnon, and J. J. Rodrigues, "An efficient blockchain-based hierarchical authentication mechanism for energy trading in v2g environment," in 2019 IEEE International Conference on Communications Workshops (ICC Workshops). IEEE, 2019, pp. 1–6.

[39] S. Wang, A. F. Taha, J. Wang, K. Kvaternik, and A. Hahn, "Energy crowdsourcing and peer-to-peer energy trading in blockchain-enabled smart grids," IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 49, no. 8, pp. 1612–1623, Aug 2019.

[40] A. Maw, S. Adepu, and A. Mathur, "ICS-BlockOpS: Blockchain for operational data security in industrial control system," Pervasive and Mobile Computing, vol. 59, p. 101048, 2019.

[41] J. Gao, K. O. Asamoah, E. B. Sifah, A. Smahi, Q. Xia, H. Xia, X. Zhang, and G. Dong, "Gridmonitoring: Secured sovereign blockchain based monitoring on smart grid," IEEE Access, vol. 6, pp. 9917–9925, 2018.

[42] J. Wan, J. Li, M. Imran, and D. Li, "A blockchain-based solution for enhancing security and privacy in smart factory," IEEE Transactions on Industrial Informatics, vol. 15, no. 6, pp. 3652–3660, 2019.

[43] Z. Su, Y. Wang, Q. Xu, M. Fei, Y.-C. Tian, and N. Zhang, "A secure charging scheme for electric vehicles with smart communities in energy blockchain," IEEE Internet of Things Journal, vol. 6, no. 3, pp. 4601–4613, 2018.

[44] M. Baza, M. Nabil, M. Ismail, M. Mahmoud, E. Serpedin, and M. Ashiqur Rahman, "Blockchain-based charging coordination mechanism for smart grid energy storage units," in 2019 IEEE International Conference on Blockchain (Blockchain), 2019, pp. 504–509.

[45] X. Huang, C. Xu, P. Wang, and H. Liu, "LNSC: A security model for electric vehicle and charging pile management based on blockchain ecosystem," IEEE Access, vol. 6, pp. 13 565–13 574, 2018.

[46] F. Knirsch, A. Unterweger, and D. Engel, "Privacy-preserving blockchain-based electric vehicle charging with dynamic tariff decisions," Computer Science-Research and Development, vol. 33, no. 1-2, pp. 71–79, 2018.

[47] E. Munsing, J. Mather, and S. Moura, "Blockchains for decentralized ¨ optimization of energy resources in microgrid networks," in 2017 IEEE conference on control technology and applications (CCTA). IEEE, 2017, pp. 2164–2171.

[48] P. Danzi, M. Angjelichinoski, C. Stefanovi ˇ c, and P. Popovski, "Dis- ´ tributed proportional-fairness control in microgrids via blockchain smart contracts," in 2017 IEEE International Conference on Smart Grid Communications (SmartGridComm). IEEE, 2017, pp. 45–51.

[49] S. Saxena, H. Farag, H. Turesson, and H. M. Kim, "Blockchain based grid operation services for transactive energy systems," arXiv preprint arXiv:1907.08725, 2019.

[50] J. Wang, Q. Wang, N. Zhou, and Y. Chi, "A novel electricity transaction mode of microgrids based on blockchain and continuous double auction," Energies, vol. 10, no. 12, p. 1971, 2017.

[51] M. Sabounchi and J. Wei, "Towards resilient networked microgrids: Blockchain-enabled peer-to-peer electricity trading mechanism," in 2017 IEEE Conference on Energy Internet and Energy System Integration (EI2). IEEE, 2017, pp. 1–5.