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Review

Next-generation blockchain enabled smart grid: Conceptual framework, key technologies and industry practices review

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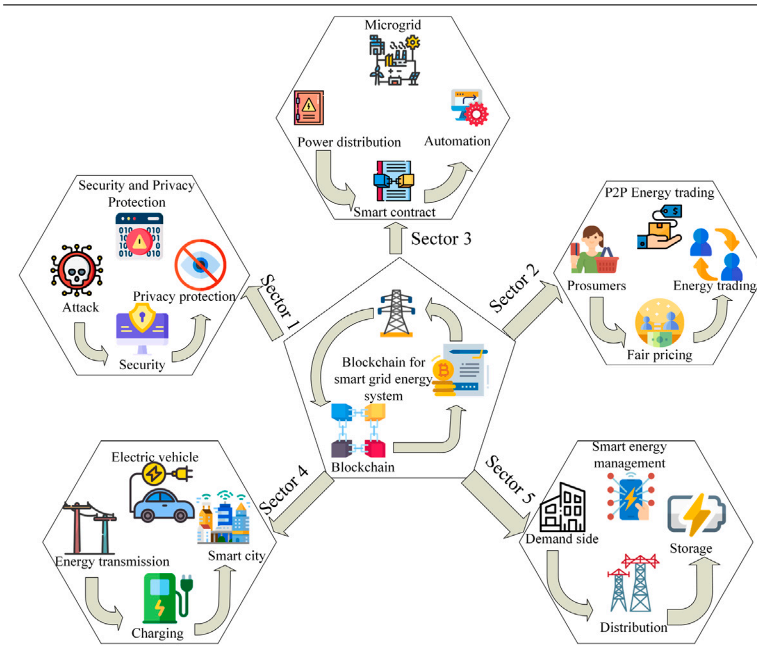
HIGHLIGHTS

- Review the development aspect of the existing BCn framework in the field of SGES.
- Emerging features of the next-generation BCn framework are discussed.
- Review the current trends of BCn framework in the real-time energy sector.
- Challenges and benefits of the next-generation BCn framework in SGES are discussed.

GRAPHICAL ABSTRACT



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ABSTRACT

Technological advancements in smart grid energy systems (SGESs) are introducing sustainable frameworks to meet the demand for the fourth industrial energy revolution. These frameworks are planned to be used in the forthcoming future to maintain the energy network operation with optimization, energy trading, grid automation, and so on. Blockchain (BCn), developing after passing a diverse period of the research journey,

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Consensus mechanism
Peer-to-peer energy trading
Electric vehicle and microgrid
Distributed energy resource

comes to the mind of researchers and its integration in SGES paves the way to reach the goal of energy demand. However, still of interest is ongoing in the improvement of BCn features which can be regarded as the next-generation blockchain framework. This paper exhibits the technical framework of the next-generation BCn framework and explores its benefits and challenges in performing the emerging aspects of SGES. This framework enables some advanced features for the sustainable operation of SGES like smart metering, peer-to-peer (P2P) energy trading, self-operation, and transparency. The technical explanation of this BCn technology established on essential features and requisites is also presented in this paper from various points of view which include smart mechanism, intelligent storage system, and interoperability. We also highlight the recent progress and limitations of the current BCn framework in SGES. Finally, some challenges towards integrating the next-generation BCn technology in SGES are reported. This work can provide extended support for the practitioner and researcher in the context of BCn technology and SGES.

Nomenclature

BCn	Blockchain
$SGES$	Smart Grid Energy System
DER	Distributed Energy Resource
EVs	Electric Vehicles
DSO	Distribution System Operator
AMI	Advanced Metering Infrastructure
DLT	Decentralized Ledger Technology
PoW	Proof of Work
$MITM$	Man in The Middle
$P2P$	Peer to Peer
$DApp$	Decentralized Application
$DPoS$	Delegated Proof of Stake
$6G$	Sixth Generation
PKI	Public Key Infrastructure
IOT	Internet of Things
EHC	Electronic Health Care
AR	Augmented Reality
VR	Virtual Reality
VPN	Virtual Private Network
TPS	Transactions Per Second
PoS	Proof of Stake
$PBFT$	Practical Byzantine Fault Tolerance
AI	Artificial Intelligence
PoL	Proof of Lowness
SC	Smart Contract
PV	Photovoltaic
DGn	Distributed Generation
$SIEGATE$	Secure Information Exchange Gateway
MDM	Meter Data Management
$IBSM$	In-system Bridge Mechanism
DL	Distributed Ledger
SMR	Smart Meter
RES	Renewable Energy Sources
CPC	Cyber–physical Communication
SHC	Self Healing Capability
DSI	Demand Side Integration
DSL	Dynamic Storage Layer
$ECDSA$	Elliptic Curve Digital Signature Algorithm
API	Application Programming Interface
$4IR$	Fourth Industrial Revolution

1. Introduction

Blockchain (BCn) enables the ultimate step towards achieving the energy sustainability of the whole world in near future. There are three parameters involved with the BCn technology; the blocks, the chain that connects the blocks together, and the transactions recorded in the participated blocks. Indeed, the transactions are merged into the blocks in a cosmic form as the BCn network is a series of blocks containing the data of the transaction [1]. The generation of the block takes place after the confirmation from the participants about the validity of the change of state causing the transaction. These blocks are chronologically connected to previous blocks to establish a synchronous chain of record to resemble the event or "blockchain" as shown in Fig. 1.

The BCn is a decentralized and distributed ledger technique developed from the "Bitcoin: a P2P voltaic cashing system" and discussed as the most sustainable technology for making reliable digital transactions [2]. Although it was primarily developed for cryptocurrency, however, a quick and wide expansion take place due to its extended feature. A new beginning point of digital currency transactions has been set by blockchain 1.0. There was no feature of the smart contract (SC) and the token system to inter-operate between multiple currencies. The prodigal mining and abject scalability of the early emerging BCn framework prompted the developer to expand the idea of BCn far-off currency. These changes lead to the emergence of the second version of BCn i.e. Ethereum based on SCs accompanying PoW consensus mechanisms [3]. However, the issue appeared with these versions is that they are struggling much to guarantee scalability as the used consensus mechanism based on PoW takes a long time to confirm any transaction.

By introducing Hyperledger and EOS.IO in BCn, the confluence towards the decentralized application was established [4]. For enabling the decentralized applications of BCn, several research areas such as governance, health, supply chain, IoT, and smart city were contemplated and successfully applied. In the current generation of BCn, it is not only constrained in cryptocurrency and digital asset areas but also used on Decentralized Applications (DApps), such as Web-based Apps VPN, Chatting, Monetary Services, Security of System, etc., [5]. However, it creates the issues of bug fixing which makes the lack of facilities for business or other technology-related platforms. Thus, the integration of sustainable applications, i.e., AI and cloud computing-enabled BCn is the key aspect of BCn 4.0 technology [6]. Services such as SC, distributed database and public ledger are the main extended feature of the BCn 4.0 technology. The sole purpose of using the SC is to eliminate paper-based contracts which increase the transaction per second. It enables the integration of different platforms in executing work together under the same umbrella. A summary of the different versions of BCn technologies with their extended feature is reported in Fig. 2. This extended feature encourages the researcher to think about the implementation of BCn for sustainable energy trading in the area of the smart grid energy system (SGES).

In this era of technology, the use of BCn in different areas is becoming popular because of its revolutionary feature, called 'Smart Contract'. The SC is nothing but an executable code shared in the whole BCn network that is triggered after completing some predefined tasks. It has made the transactions among the nodes in the BCn automatic and also ensures the validity of the transactions. As this technology provides the inherent feature of transparency, immutability, security without

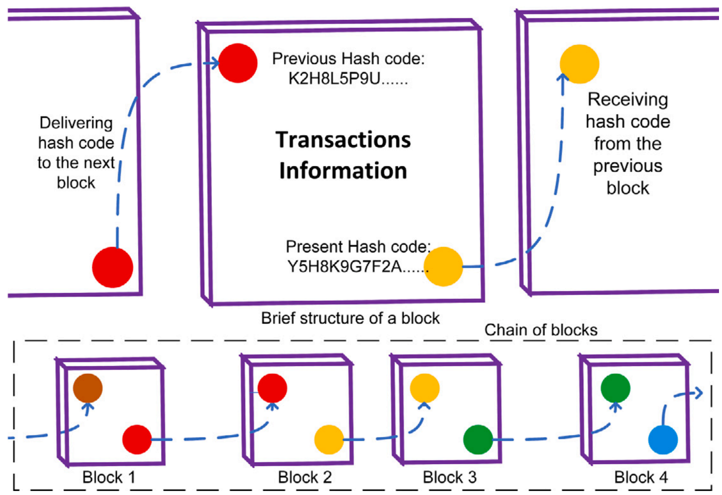

Fig. 1. General Structure of Blockchain.

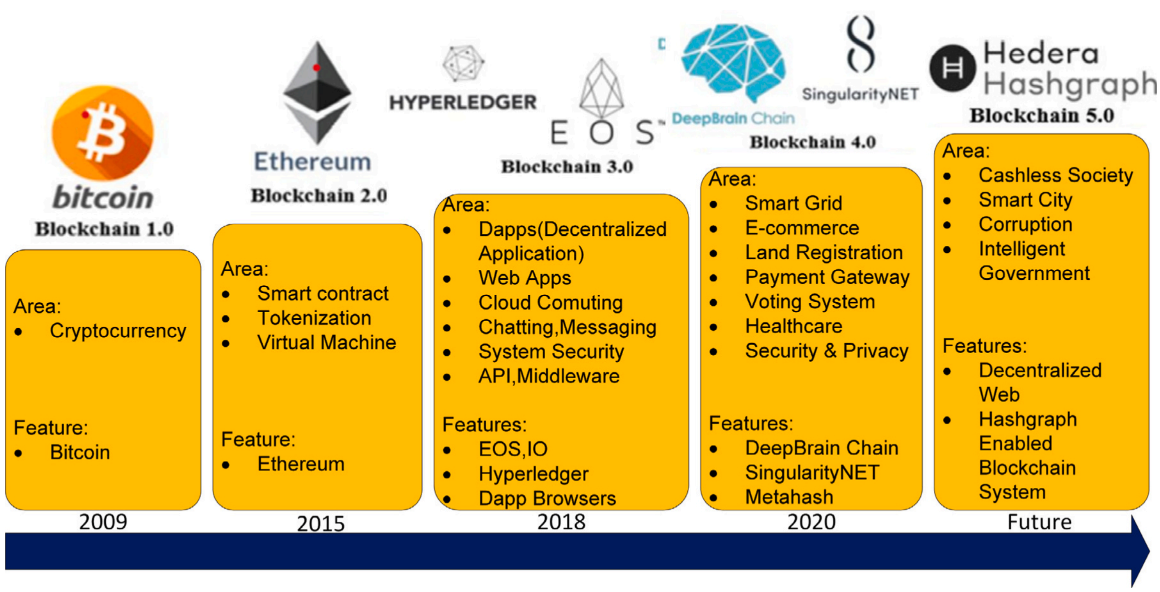

Fig. 2. Evolution of different versions of BCn technologies with the extended features.

involving any third party, audibility, and resilience, it is now highly preferred technology for all the potential sectors like banking [7], medical [8], education [9], IoT implementation [10], energy [11] and so on. In the energy sector, it can facilitate the SGES by the trading of electric power, managing the grid automation/distribution power network, and integrating heterogeneous energy sources with the SGES.

SGES is basically, the technology that incorporates three entities such as smart energy generation [12], distribution, and transmission systems in a single framework [13]. The main purpose of this system is to facilitate P2P energy trading [14] by decreasing the dependency on the central power grid and/or single authority. Also, the feature of SGES in distributed generation solves the problem of loss of the long-distance transmission of power, and the lowered quality of the power. Over the conventional grid systems, it has the feature of energy trading using smart meters [15], distributed generations, incorporation of renewable energy, double way communication system between consumers and prosumers [16], carbon emission contraction, and so on. Not only the ‘Smart Contract’ based energy trading facilities, but BCn with its many other features also facilitate the many other operations for SGES, such as automation of grid, security of the data, transparency of the data, the autonomy of the consumers and prosumers, sharing receiving power by charging of autonomous vehicles, etc. The development of BCn framework in the energy sector had to go through a long journey from a single cryptocurrency-based algorithm to come out at the present stage as shown in Fig. 3.

Although the existing version of the BCn is popular in the energy sector, however, some problems still exist in this technology in case of power consumption, time per transaction validation and block generation, indirect centralization, lack of heterogeneity [17], interoperability [18] etc. These issues create additional challenges at the time of implementing the BCn technology in the mainstream applications like sustainable SGES. These challenges are the availability, integrity, confidentiality, authentication, authorization, irreversibility, audit, and accountability of SGES [19]. The appearance of these challenges in BCn technology-enabled SGES initiates the contemplation of next-generation BCn by incorporating a revision in the context of the existing feature. The next-generation BCn technology may have the features of a new consensus mechanism, intelligent storage management system, enhanced interoperability and heterogeneity, inter-chain smart contract algorithm, and so on. This paper demonstrates the technical framework of next-generation BCn technology applied in SGES in terms of improved consensus mechanism, data management technology, and improved SCs algorithm.

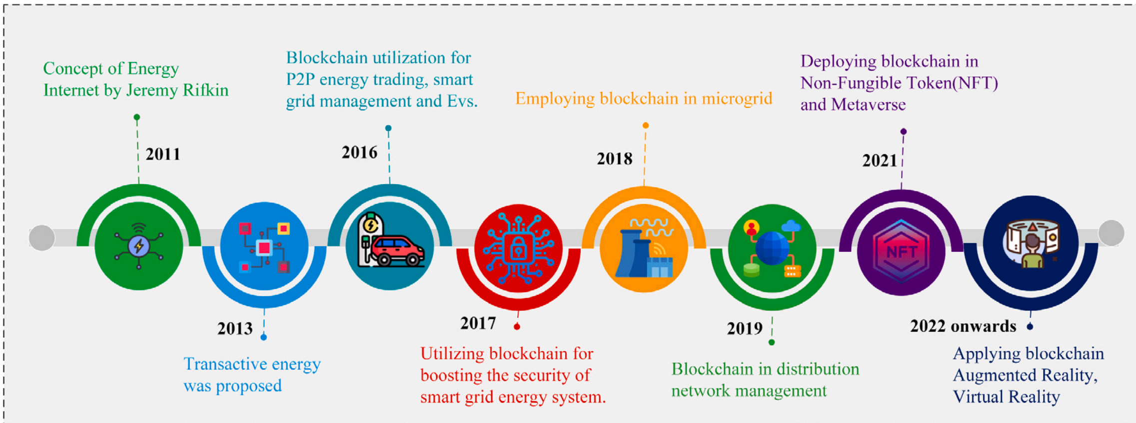

Fig. 3. Application and improvement timeline of blockchain technology in the energy sector.

Table 1
Summary of literature surveys [20–28].

Reference	Investigate the problems of existing BCn framework	Develop possible framework for next generation BCn	Study the trends of BCn in SGES	Explore benefits of next generation BCn in SGES	Integration challenges	Future direction
Yapa et al. [20]	✗	✗	✓	✗	✓	✗
Mollah [21]	✗	✗	✓	✗	✓	✓
Aderibole [22]	✗	✗	✓	✗	✗	✗
Musleh [23]	✗	✗	✓	✗	✗	✗
Aklilu and Ding [24]	✗	✗	✓	✓	✗	✗
Hasankhani [25]	✗	✗	✓	✓	✓	✗
Kuzlu [26]	✗	✗	✓	✗	✗	✗
Hasan [27]	✗	✗	✗	✗	✓	✗
Wang [28]	✓	✗	✓	✓	✗	✗
Current study	✓	✓	✓	✓	✓	✓

1.1. Motivations and contributions

According to the important surveys addressed in Table 1, it is realized that there are many scopes and applications of BCn in the SGES. The role of BCn technology in SGES is to facilitate the many advanced features, however, the absence of these features hinders the scalability, availability, security, and other issues. Many of them show the additional challenges that may arise while implementing the BCn framework in SGES. However, these studies are not focused on the development of the present BCn technology even after BCn 5.0. As in the present case scenario, there are many loopholes in the system and it is necessary to study these drawbacks in order to solve them by improving the present BCn technology. It will facilitate the SGES more with high scalability, data availability, high security, cost efficiency, interoperability, etc. The contributions of this study involves are:

- ***Investigate the problems of existing BCn framework:*** In this paper, we have discovered the flaws of the previous and current versions of Blockchain and investigated the issues that appeared in the currently executed techniques governing the BCn-based SGES.
- ***Develop a technical framework for next-generation BCn:*** We explored possible solutions for the major issues of the present BCn framework by developing a technical framework of next-generation BCn. This is done by enabling the smart consensus mechanism, and intelligent storage system, and enhancing interoperability capability in the BCn landscape.
- ***Study the trends of BCn in SGES:*** A brief introduction about the feature and technology of SGES is studied in this paper. This study clears the trends of BCn technology in the SGES. Also, we investigated the projects of some of the leading agencies, working on integrating BCn and the energy sector at different times, and mentioned their span in this sector.
- ***Explore benefit of next-generation BCn in the SGES:*** A brief discussion is given about the barriers facilitating SGES with the present BCn technology. Also, we highlighted the importance and benefits of implementing the next-generation BCn framework in SGES.
- ***Integration Challenges and Future Directions:*** Like every other technology with very high potential, some challenges appeared at the time of integrating the next-generation BCn and SGES technology. The scope of addressing these challenges enabled the future direction toward the next level of research opportunities for the work.

In section two, we have discussed briefly the fundamentals, features, and technical policies of BCn technology. Here we mentioned how BCn technology works, the fundamental features of BCn technology, the technical policies of BCn, the core technology of BCn, and finally some fundamental applications of BCn technology. In Section 3, SGES and the different prospects of its implementation with BCn networks are discussed. On one hand, the BCn facilitates the conventional SGES. On the other hand, there also exist some gaps too. The gaps are mentioned here while the solutions of them with the future BCn framework are discussed in Section 4. The future framework and its add-on features are also discussed in Section 4. Also, in Section 4, we mentioned the barrier to implementing the BCn with the SGES. Because of the barriers, the direction of the future solutions and work on them are shown in the next section.

2. Blockchain: Fundamentals, features and technology

Blockchain is primarily developed for transactions of the cryptocurrencies like Bitcoin and Ethereum. However, due to the extended features of BCn technology, its applications spread quickly in various

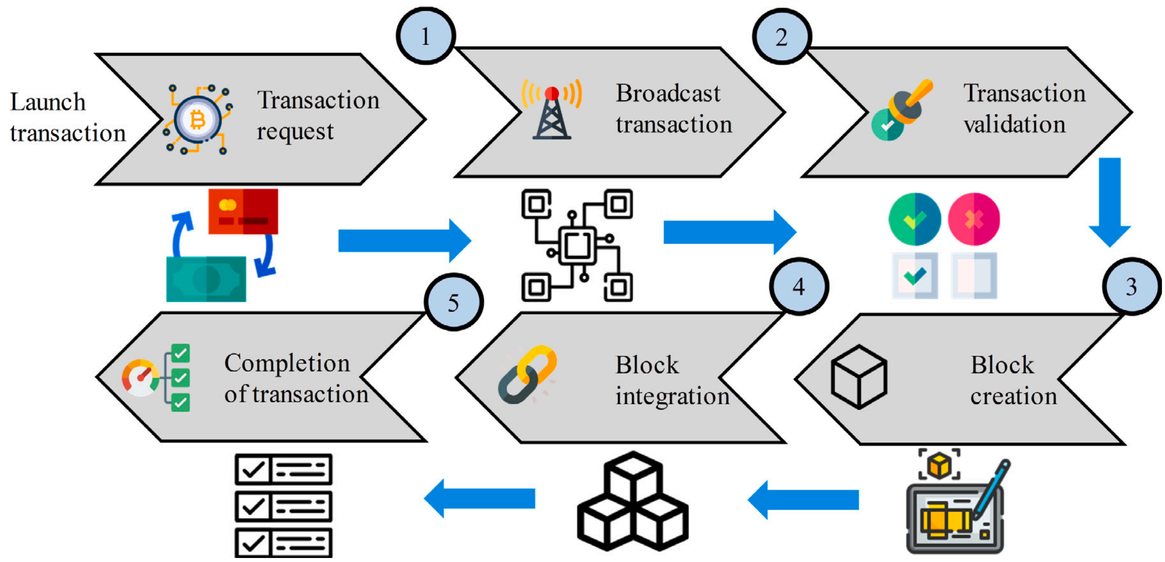

Fig. 4. Blockchain technology working mechanism for executing the complete transaction.

sectors [29]. A transaction using the BCn technology is occurred by enabling the four secured steps upon the request of the consumer as shown in Fig. 4. The first step, called the broadcast layer, passes transaction information to all the nodes connected to a chain. In the actual transaction procedure, the nodes can trade so as above 51% of the nodes receive this information. When a node gets inaccurate data and declares that the transaction information is incorrect, the node will discard the message and not broadcast it.

In the next process of BCn operation, the idea of "Mining" comes to the front which enables the entire BCn network to execute the operation based on the intention of earning additional tokens. Here, miners are those who are being compensated for working as auditors and verifying whether the Bitcoin transactions are valid. Now, the BCn networks create the block through the use of a validated finished transaction verified by enabling the consensus mechanism, and this process occurs at the time of passing the third operating layer. As the records of the transaction are not immediately placed inside the block as plain text, the hash function, and Merkle tree is considered to handle them in the block formation process [30]. In the last layer, the evidence of every transaction is saved, which means it cannot be changed randomly. Thus, it creates a chain structure by the orderly connecting of blocks that maintain the information and records of the associated finished transactions.

2.1. Features of blockchain technology

The extended feature of the BCn network creates a mixed feeling about this spotlight technology around the world, and its function undoubtedly contributed to the enhancement of global economic topography. The special features of BCn network are decentralization. anonymity, trustworthiness, reliability in data storage, transparency, democracy, and more security [31]. In practice, data management in a centralized controllable network is highly risky to offer data credibility and transparency. However, the decentralized nature of BCn technology makes it easier to handle real-world data with more credibility, transparency, and security. In the decentralized distributed ledger system, the anonymity of the clients or users is maintained with very dependency. There are two keys named private and public keys. With the help of those keys, the private data are kept private and only the data or information that are needed to be seen by anyone are kept public.

Another indicator for accepting the BCn technology is its trustworthiness [32] as any particular person or central authority is not in charge here. The whole system runs on the basis of previously made smart contracts, consensus algorithms and so on which cannot be manipulated [22]. More specifically, the transactions between the users are controlled and maintained by a highly secured computer network, not any central organizations or authority. Additionally, the BCn technology can show reliability [33] in storing the data. In the traditional or general distributed data storage system, the central authority divides the data into several parts. However, in the case of BCn, every node individually holds data and stores them as a person or an organization inside the network. Each block can store the data listed for the records of the transaction. The new block also gets all transaction information during the block creation. Further, the trading operation of BCn network is done in a transparent way that an update of information requires authentication from all the connected nodes. No central authority is responsible for transactions. It does not have any centralized control hub so each node can hold the same power and accountability [34] which signifies democracy, i.e., each node can become a supervisor, nature of the BCn network.

2.2. Technical policies of blockchain

Blockchain is an emerging technology-oriented system carrying a number of different technologies such as data storage systems, symmetric encryption techniques, and consensus mechanisms. The following section provides a comprehensive overview of the technological fundamentals used in BCn network.

2.2.1. Asymmetric encryption algorithm

In BCn technology, asymmetric encryption technique is considered for the security requirements and ownership verification as shown in Fig. 5. This encryption technology can provide more security than other techniques because it can initiate a security constraint by enabling the public and private keys. The connection between these two keys is that the public keys are generated from the private key. After that public keys are used to generate the open hash value which eventually produces a wallet address [35]. The entire process of asymmetric encryption is maintained through a complicated algorithm that defines the efficiency, reliability, and strength of the algorithm. However, as the algorithm gets complicated, the process or system slows down gradually.

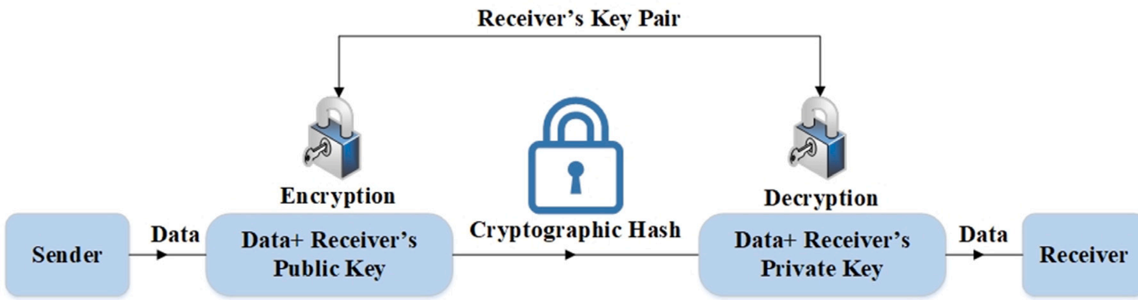

Fig. 5. Asymmetric encryption algorithm used in security for BCn technology.

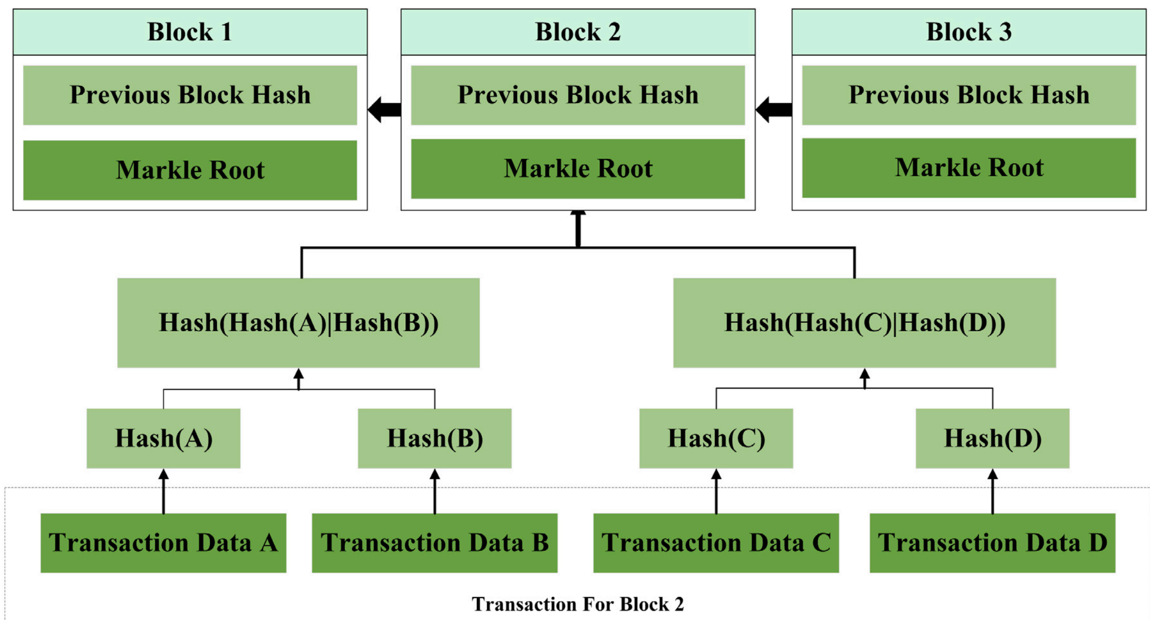

Fig. 6. Structure of the Merkle tree used for the data synchronization in BC nodes.

2.2.2. Distributed data storage

It can store each transaction data independently which is then distributed and synchronized among all the nodes to maintain authenticity and transparency. The data synchronization is maintained by a method called Merkle tree as shown in Fig. 6. It is basically one kind of binary tree with different nodes called Root nodes, intermediate nodes, and leaf nodes. The leaf nodes contain the generated hash value from the intermediate nodes and send it to the hash value in the root node. As long as the root node is known, tampering with any node's hash value is quite difficult because the hash value does not match with the root node. Thus, this structure can maintain a large amount of generated data smoothly and retain transparency [36].

2.2.3. Smart contract

Smart contract (SC) layer is used to create the business terms, conditions, and logic for the BCn network in terms of code as shown in Fig. 7. It operates the triggering of the conditions and executes the rules automatically set by the terms, conditions, and logic to complete every transaction. The higher value of the triggering conditions makes the smart contract stronger [37]. The main object of this operation or value is mostly in the form of digital assets. When the data is chained after triggering the conditions and execution of the rules, it is quite difficult for anyone to modify this. At present, the extensive use of SCs has made the identification of how to minimize the risks, and create value very challenging. The SCs are of two types named Turing complete and non-Turing complete. The non-Turing complete SCs have fewer security issues as they are simple in logic. On the contrary, Turing complete SCs are very adaptable and widely used due to their ability to deal with complex types of logical business problems such as restricted loop operations or recursion of the operations [38].

2.2.4. Data storage structure

In BCn, all the blocks or nodes are distributed geographically and each node holds a copy of the distributed ledger in the entire network. At the time of creating a new block, it is validated by all the nodes whose transactions are present or added to the ledger, and the ledger is synchronized among all the connected nodes. A block is made up of two main parts: a block header and a block body. The header is for linking with the previous block to maintain the validity of the previous transaction data while the body part is used to store all the authentic transaction records via a special data structure called Merkle tree [39,40]. The structure is shown in Fig. 6

2.2.5. Network protocol

Each computer/node in the BCn network is linked with one another under the same network without the presence of any special node. This feature is ensured by the Peer to Peer (P2P) protocol. As there is no central authority or server, the network is naturally free from attacks and tolerant of any kind of fraud [41]. There are no specially treated nodes in the network protocol of BCn technology. All the nodes keep the same manner towards the algorithm and get the same service from this network. As result, by attacking some particular nodes, the

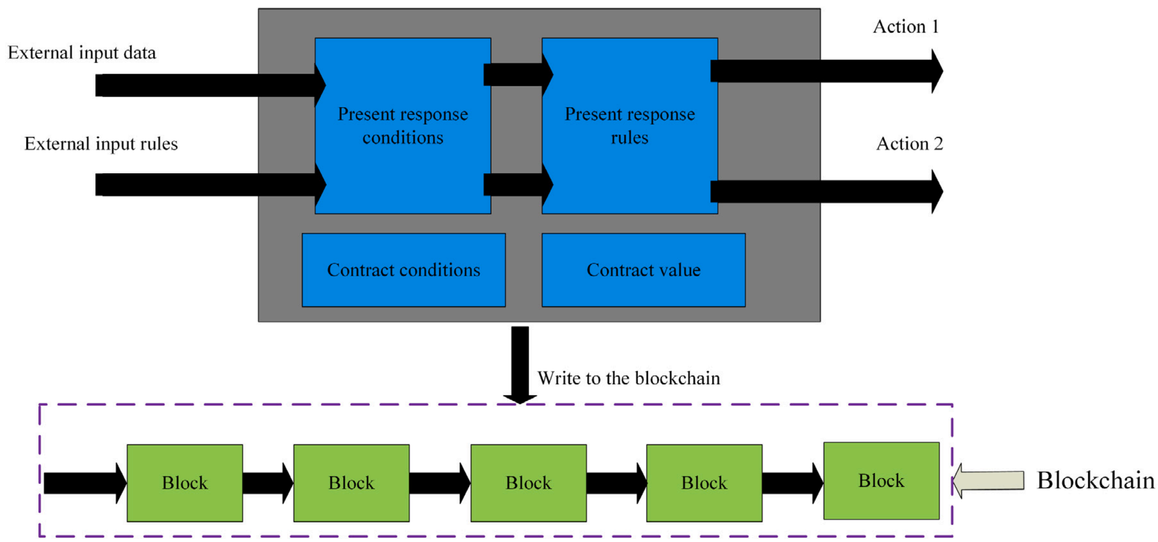

Fig. 7. Smart Contract Model.

attacker can affect the whole network very little or not at all. Different P2P protocols can be developed and adopted by different blockchain systems according to their network protocol [42,43].

2.2.6. Distributed ledger

Distributed Ledger(DL) is a technology for storing data of decentralized transactions and allows data to be shared, synchronized, and replicated over the network where numerous nodes are available. Such nodes can be representative of some persons, physical locations, or any organization. The DL technology has two distinct properties when compared to the typical distributed storage systems [44]. First, in the modern world with the highly increasing rate of internet data, it is becoming quite difficult to manage them for any central organization. The complexity is also growing heavily with the growth of the data sizing which reduces the dependability of the centralized. In this scenario, the decentralized/DL can handle all these pressure and effectively maintain the lower load, complexity, and cost. Again, the general distributed data storage system has the central authority that divides the data into several parts and stores them. However, the DL technology enables a way in which every node of the BCn network individually holds data storage as a person or an organization [45].

2.2.7. Encryption algorithm

The distributed ledger-based BCn network provides security of privacy to a larger extent. For this, it extensively uses modernized information security which includes symmetric and asymmetric encryption [46], digital certificates and hash algorithm [47]. The term "Data Digest" is the one kind of hash algorithm [48]. The principle of this hash algorithm is to transform a piece of data into a string of fixed length which keeps the data safe from unauthorized access. A feature extraction technique named "Data feature" is also considered the prime concept of the encryption mechanism as the necessary information needs to be extracted from the string of fixed length.

2.3. Core technology used in blockchain network

2.3.1. Consensus mechanism

The reason behind the application of the consensus mechanism is to address the consistency issues that may appear in distributed ledger systems associated with BCn network. This algorithm solves the problem by identifying the initiator node of the proposal and the approach to reaching the agreement by all nodes. It consists of using the following mechanism.

(i) Proof of Work mechanism (PoW): The key concept beyond this technique is to make an additional new block and nodes requested to deal with cryptographical puzzle [49], called as PoW issue that is not easy to decode, but easy to validate. When the problem has been solved, it is hooked to that new block and broadcast across the network for the validation of the new block, simply known as mining.

(ii) Proof of Stake mechanism (POS): In PoS, the concept "mining" is eliminated through the "validating" [50]. It can decrease the mining difficulty of nodes. This mechanism randomly chooses the evaluators to make the blocks. The PoS is not only time-efficient but also energy-efficient compared to the PoW algorithm.

(iii) Delegated Proof-of-Stake mechanism (DPoS): It is a modified form of PoS where each node can delegate the validation of transaction to another node by voting [51]. So it is an elective consensus mechanism that follows a representative democratic approach.

(iv) Practical Byzantine Fault Tolerance mechanism(PBFT): This algorithm is capable of enduring Byzantine Faults of certain nodes being dishonest and can rely on the trusted nodes [52]. A detailed explanation of the steps to find the fault can be found in [53].

The percentages of adoption of BCn technology on the basis of different consensus mechanisms are represented in Table 2.

3. Blockchain in smart grid energy system (SGES): Framework and trends

3.1. Essential technology for SGES

Smart Grid Energy System (SGES) refers to a concept that incorporates three entities such as smart energy generation, distribution, and transmission systems in a single framework [66]. It is an integrated system that integrates information passes through the two-way cyber-secure communication technology, and applies computational intelligence throughout the whole process of the energy system, i.e., from generation point to the end consumer of electricity [67]. The integration of photovoltaic(PV) systems and wind farms together with essential control technology into the electric grid, as shown in Fig. 8, improves reliability towards the uninterrupted power supply and also enhances system resiliency during and after extreme events. In recent years, the SGES has become a spotlight energy technology, and no one can deprecate the impact of SGES in the energy economic landscape due to its extended features explained in the following section.

Table 2
Blockchain use cases in the energy sector.

Used cases according to consensus mechanism applied		Used cases according to activity field		Used cases according to BCn platform	
Consensus mechanism	Percentage	Activity field	Percentage	Platform	Percentage
Proof of Work (PoW) [49]	55%	Decentralized energy trading	33%	Ethereum [54]	50%
PBFT [53]	15%	Cryptocurrencies, tokens investment	19%	Hyperledger [55]	11%
Proof of Authority (PoA) [56]	13%	loT, smart devices, automation & asset management	11%	Energy Web (Ethereum- based) [57]	10%
Proof of Elapsed Time [58]	3%	Metering, billing & security	9%	Tendermint [59]	7%
Federated Byzantine Agreement [60]	2%	Grid management	8%	Interbit [61]	2%
Proof of Capacity (PoC) [62]	2%	Green certificates & carbon trading	7%	Keyless signature infrastructure [63] (KSI)	2%
Round Robin based [64]	2%	Electric e-mobility	7%	Qtum [65]	2%
Others	8%	General purpose initiatives & consortia	6%	Others	16%

3.1.1. Energy trading using smart meters

Smart meter (SMR) [68] is a distinct feature of SGES technology and is considered the dependable device for the measurement of information in energy production, distribution, transmission, and consumption [69]. It incorporates a communication system with digital meters for real-time monitoring of consumed energy [70]. By SMR reading, the consumers can be able to manage their consumption of electricity according to their budget [71]. For suppliers, distributors, and consumers, the SMR acts as a common point of contact and establishes a safe connection between SMR and utility servers as it can influence transaction and billing data. When multiple stakeholders get engaged in the trading process, the report of a transaction should be maintained by a reliable third party that can be solved by applying BCn technology in SMR-enabled energy trading.

3.1.2. Distributed generations

SGES highly depends on distributed generation (DGn) [72] which produces decentralized on-site electricity in the generation system. The establishment of a large number of power plants causes some unavoidable consequences, i.e., the effect of environmental change on transmission lines and distribution systems. As the demand for electricity is increasing rapidly, the present network of the electricity production system is losing its efficiency due to transfer the of a large amount of power. Thus, the conventional approaches contribute to the existing network's complexity. To fulfill customer demands in the distribution system, such as low bills, reliability, the safety of data, and an in-depth diagnosis of SGES components, the DGn-driven smart energy system is mandatory [73]. This can help reduce operating costs as well as increase the efficiency, reliability, and security of the power generation system [74].

3.1.3. Control system to incorporate of RESs

The DGn technology in SGES uses renewable energy sources (RESs) such as photovoltaic(PV) systems or wind farms for producing electricity [75]. As SGES integrates multiple RES as the source of driven power, it is also known as Green Grid [76]. The purpose of integrating various RESs in SGES technology is to reduce the CO_2 emission [77] to the environment and ensure a reliable power supply to the consumer during and after extreme events [78]. However, the stochastic nature of RESs produces an undesirable performance of SGES technology which may solve through the integration proper control system [79]. The purpose behind the use of the control technique is to offer the reliable performance of SGES over the variable nature of RESs [78].

3.1.4. Double way communication system

The SGES system becomes effortless for both distributors and customers because it uses a two-way communication system [80]. In a bidirectional communication system, consumers get alert of the price of consumed energy, and consumption of the energy, as well as the amount of generated electricity by the distributors, get informed about the price of the consumed electricity [81]. Communication channels such as UART, and Ethernet are used as cyber–physical communication (CPC) systems in SGES networks [68]. For safety issues of the CPC interface, the IEE C37.118 [82] and secure information exchange gateway (SIEGATE) have been produced and introduced [27].

3.1.5. Automatic healing capability

As SGES is a technique for the generation and distribution of electricity as well as having a large level of data security and robustness over uncertainty [83]. The self-healing capability(SHC) of SGES [84] is an exclusive feature that makes the entire system stable through the characterization of unexpected system states such as fault, overflow of current, and fault revival capability [85].

3.1.6. Data management system

The information management system of the smart meter is a necessary part of the advanced metering infrastructure (AMI) [86]. A software named "Meter Data Management(MDM)" is used to store and manage a large amount of data generated by SMR systems [87]. The entire management system connects with the field area network which plays a vital role to build impenetrable connectivity between several field equipment, such as transformers, distributors, smart electronic devices, and sensors. The adoption of BCn technology on the basis of use cases in different fields is represented in Table 2.

3.2. Trends of BCn technology in SGES

BCn technology is a cryptocurrency-based, decentralized digital trading system with immutability, anonymity, transparency, and resiliency. This is an exemplary solution to face the existing challenges of SGES as shown in Fig. 9. SGES including several power transactions in a non-centralized framework offer trends to implement BCn technology.

3.2.1. Peer-to-peer (P2P) energy trading

This is a paradigmatic solution to ensure a secure connection for energy trading for the individual consumer. The P2P trading between the consumer and prosumer (producer + consumer) in a native microgrid is executed through the distributed framework. All of the transactions is recorded in a transparent and immutable way to all the participants with the latest copy carried by every node [88]. Besides, user verification and the safety of data are guaranteed via cryptographic encryption [89]. The utilization of BCn technology increases the application of available sources and decreases the adverse effects on the environment. The P2P energy trading based on BCn network provides the authentication of the information being exchanged, and the capability to make secure transactions between unknown parties, which are not traceable. Again, smart contracts in BCn provide a self-governing energy exchange process by closing out the role-play of Distribution System Operators(DSO).

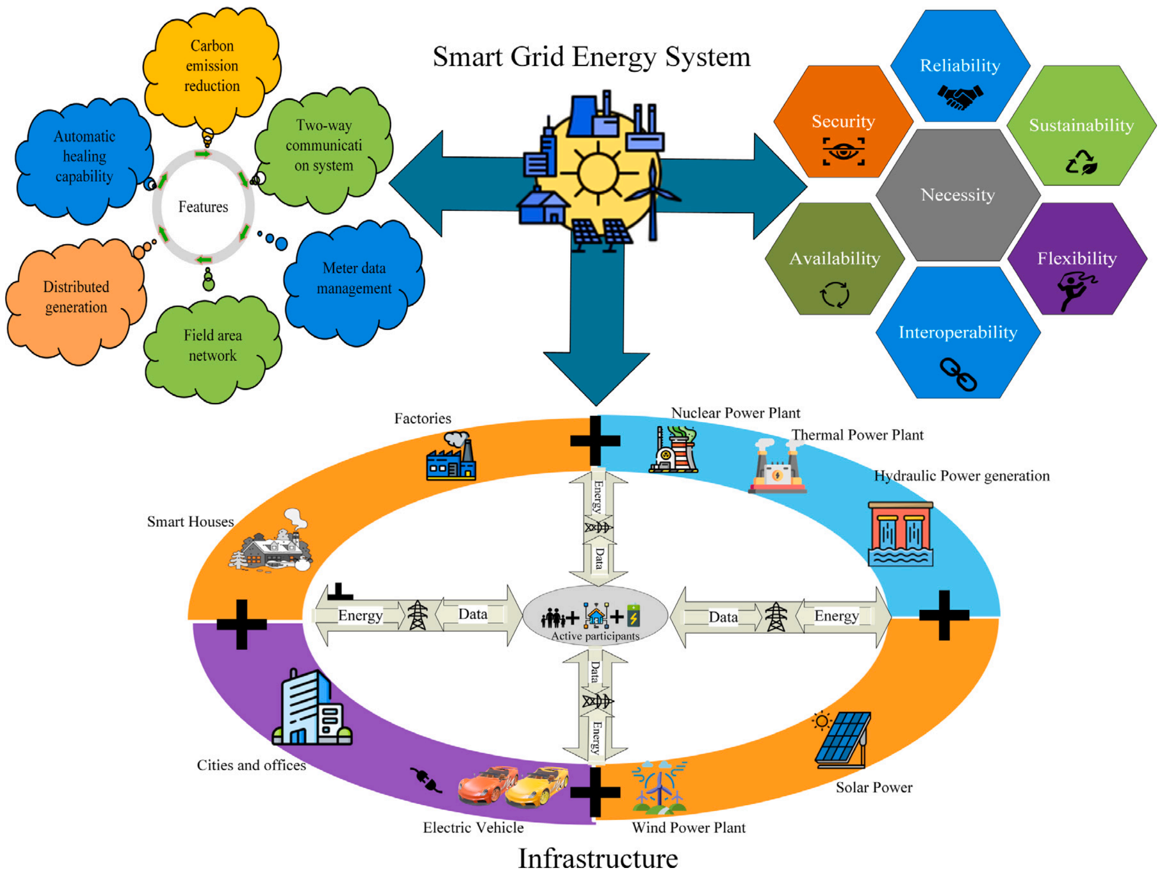

Fig. 8. A structure of smart grid energy system showing its energy sources, necessities and features.

3.2.2. Plug and play interfacing of DERs

BCn can be applied to boost renewable energy production projects, which provides advantages for both consumers and prosumers. Here, real-time energy pricing without the intervention of any third party can be obtained via the implementation of a dynamic smart contract which provides the flawless integration of DERs. Again, the pseudo anonymity feature of BCn network discloses the identity of users and their location, which ensures the prevention of fraudulent activities [20]. Further, the deployment of smart contracts on the BCn platform is useful to synchronize the distributed optimization algorithm to gain the global energy optimum [90].

3.2.3. Microgrid

BCn technology has the prospects for providing advantages for every stakeholder in the SGES [91]. The prosumers may have to create a rule to trade energy. They will be rewarded if they fulfill the agreement otherwise they will have to be penalized for the violation of the agreement [20]. Monitoring of the prosumer agreements, faultless payment handling, transparent information storage, documenting the amount of energy generated and fraud prevention are referred to as the privileges gained via the integration of BCn in the working process of microgrids [92].

3.2.4. Programs of demand side integration (DSI)

Real-time balancing of supply–demand can be achieved by the application of DERs when BCn provides flexibility services to the DSO [93]. This technology offers a balancing of energy via its safeness, transparency, and unalterable data recording abilities to prevent the insertion of suspicious data. All participants will be able to see the grid interactions of several energy stakeholders. In this way, balancing of power can be achieved by BCn dependent on a translucent load scheduling system. Additionally, the self-governing smart contracts precisely specify the energy consumption profile for every consumer [94]. Meanwhile, it can empower a scheme to reward consumers who utilize renewable energy production resources to meet their demands.

3.2.5. Grid automation

The automation process of the grid can be emphasized by the integration of BCn technology, although AMI plays an important role to facilitate it. The primary transaction that occurred in the conventional grid is the root cause of adapting BCn [88]. As a result, the requirement of the third party is eliminated, and thereby, latency resultant of processing delay and related cost expansion is reduced to a great extent [103]. BCn further provides the unification of all information related to transactions which reduce the data processing time, otherwise, the vulnerability to cyber-attacks may get increased [104]. Through the application of BCn, the energy-generating units can directly communicate with consumers to execute self-governing energy transactions, which eliminates the necessity of third party [88]. Additionally, the SCc can be used in implementing the financial settlements while BCn is utilized in recording transaction information [105]. The usage of energy and data for diagnosis is calculated and stored in a tamper-proof and distributed form. This will be used for billing, management, and monitoring of demand response [106].

3.2.6. Network management distribution

BCn can be applied to simulate the future framework for the power grid. The simulated records can be employed to overcome the limitations of the grid during the bottlenecks of the network. DLT is used to broadcast the availability and resiliency of the grid resources while BCn technology ensures the security and clarity of the transmitted network [107].

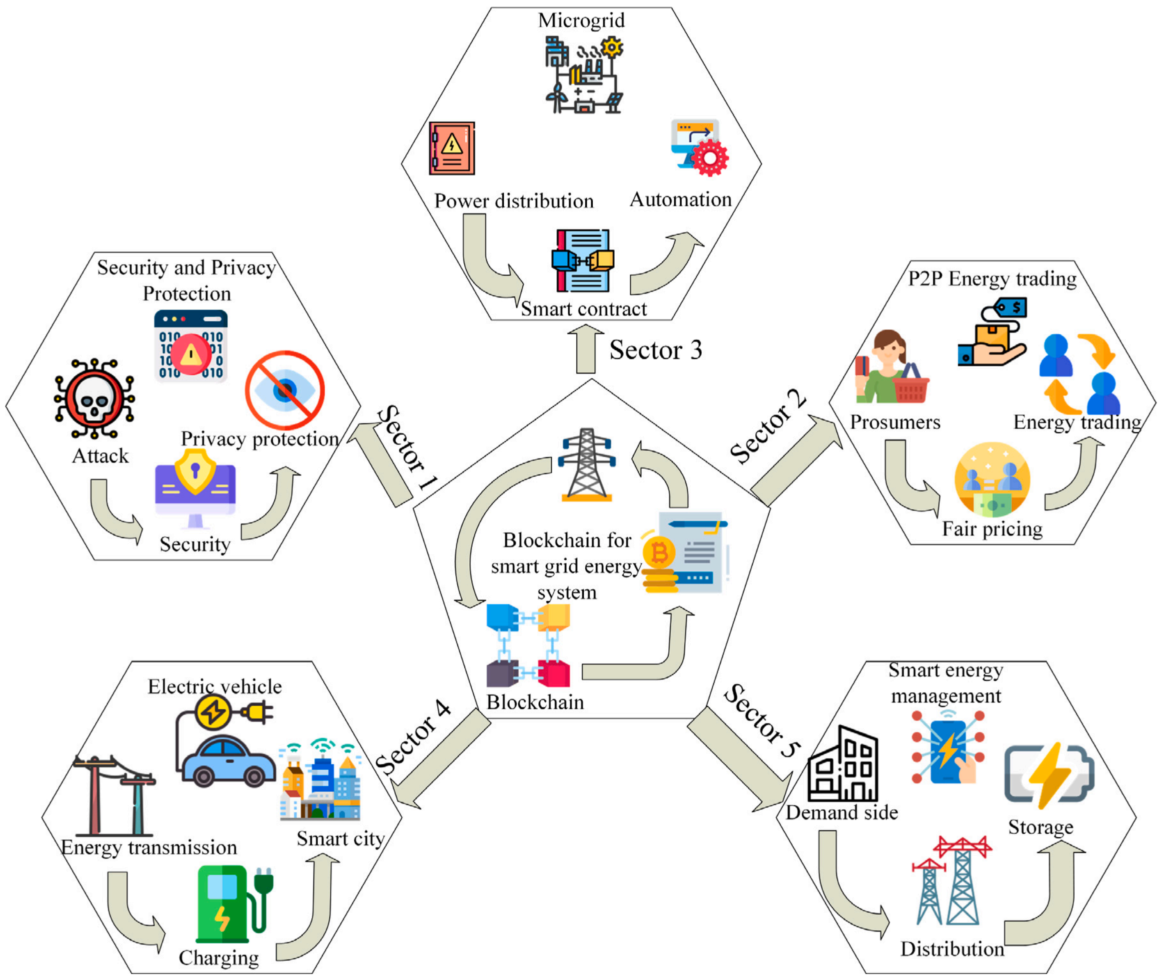

Fig. 9. Blockchain technology-enabled smart grid energy system.

Table 3
A summary of BCn network trends in smart grid energy system.

Necessity	Explanation	BCn regulated output
Decentralized framework [95]	RES, EVs and battery storage systems can be regulated with a low degree-of-freedom and maintained via a central entity.	The working mechanism of BCn is decentralized and trust factor is displaced by cryptographic.
Open structure [96]	A party who accomplish the necessity of the grid interconnection is allowed to interchange energy and information.	Public BCn is open to all participants and a copy is ledger is regulated by each of them. Private BCn allow specific nodes to access information.
P2P transfer [97]	Interchange of energy and information is executed between a consumer and a prosumer without intervention of any third party.	BCn is initiated to perform transaction among two nodes without any central authority to establish trust.
Self-operate [98]	RES, energy storage systems are required to be integrated to obtain a self-governing grid framework so that involvement of central authority can be eliminated.	Smart contracts carry a list of guidelines, pre-authorized using the consensus technique of all participants, once the rules are met.
Interconnected [99]	Consumers can be turned producers, so it has the ability for being connected each other i.e., utility network and consumers.	Nodes of all participants can occur transaction among each other.
Shared database [28]	Real-time energy data interchange is required to perform operation of autonomous grid.	In BCn, transaction are done in a chronological form and distributed among allowed nodes.
Transparent [100]	Accountability of transaction along with security and immutability of information is kept.	BCn provides transparency with immutability via DLT
Equality [20]	A level playing field has been created for all stakeholders by SGES.	BCn verifies the user identity and integrates any trusted stakeholder.
Loss of Governance [101]	Single-owner cannot be allowed and single-point-failure has to be prevented.	Operation of BCn is executed with in a self-governed nature with distributed authorization to ensure integrity and security.
New Stakeholders [102]	Includes heterogeneous energy sources of various capacities.	Cryptographic features are employed in BCn to ensure secure transactions among trust-less parties without any involvement of middle man.

3.2.7. Energy data regulation

Aggregation and exchange of data claims for security and scalability are provided through the integration of BCn-based platforms. The management of aggregated data can be achieved through the utilization of BCn platforms, which can prevent the illegal trading of sensitive information [108]. To establish trust among stakeholders and real-time circulation of data, BCn can be a good choice due to its extended features [109]. BCn provides the architecture for recording all the transactions in a tamper-proof and decentralized ledger [110]. As a result, dependency on the central authority is eliminated. Security features of BCn help to get clear and unaltered data from a genuine source of information. A summary of the trends of BCn network in the smart grid energy system is reported in Table 3.

3.3. Blockchain adaption in real-time energy sector

Recently, several projects based on BCn technology have been initiated by the companies involved in energy and utility companies. The BCn platform is primarily used for only secure and transparent energy trading like P2P transactions using secured encryption algorithms, distributed consensus mechanisms, etc. It can also be implemented for grid maintenance, carbon emission tracking, a certificate for contribution RE, token methods, IoT integration, etc., [111]. The scopes are still theoretically possible, but ongoing projects are not mature enough till now to implement all these. But many simulations and testing are going on to ensure the feasibility, stability, and reliability of the projects. Some of these projects are explained here. Table 4 shows the agencies using BCn on energy applications.

3.3.1. PowerLedger (Australia)

PowerLedger, an Australian company, conducts several projects on the basis of EcoChain; a private BCn system established in 2016 to 2017. This company developed and displayed the first project for P2P energy trading based on BCn technology in western Australia at Busselton [112]. It enables the interoperability between the electrical units (kWh) and the pricing system of electricity. This facilitated many applications like EV, carbon emission tracking, etc. that include a decentralized network for the increasing number of users based on the development of a dual token ecosystem by a modified Ethereum BCn consortium. The tokens were POWR and Sparkz [111]. The POWR worked on the PoW consensus mechanism and Sparkz worked on the PoS consensus mechanism of BCn technology. The hosts and the participants needed a POWR token to use the platform and the other token Sparkz was used for transactions. The end users in the network do not need to have POWR tokens. They need to just convert their fiat currency into Sparkz and conduct the transactions. However, to generate the required amount of Sparkz for the customers, there must be a sufficient number of POWR tokens in the system.

PowerLedger uses two layers, public and private. The public layer permitted to use of Ethereum of BCn to establish links with other grids that have other token systems. The second layer was for energy trading among the entities includes in that specific chain only. Recently, PowerLedger shifted from Ethereum-based BCn towards Solana which is much more efficient. Instead of the PoW consensus mechanism, Solana uses PoH (Proof of history), and PoS. It is faster and has a very transaction rate of more than 50 thousand transactions per second, and it takes 400 ms to create a new block [113]. To promote the use of RE PoewerLedger, runs several projects in India [114], Thailand [115], North America [112] and many others.

3.3.2. LO3 energy: Brooklyn microgrid (USA)

Transactive Grid constitutes of LO3 Energy, Centrica, Consensys, and Siemens, and runs a BCn based platform for P2P energy trading named as Brooklyn Microgrid (BMGD) [78]. It is a pilot project launched in April 2016 to deliver real-time metering data of the energy generation locally to the local MG [88]. They conducted P2P transactions between consumers and prosumers through MG wire [105]. It is not only implemented in the US but also works actively in Japanese energy markets. Primarily, it is a private BCn system based on Ethereum conducted by Terdermint based on the PBFT consensus mechanism. Though it has the possibility to be open for everyone for using energy from RES, this platform is especially expert for the applications of BCn in the SGs. A new project, Exergy is also developed by LO3 Energy to manage the grid [116] cloud more effectively by reducing energy losses. It will provide the features of automatic response to overload, short circuits, and real-time metering. ERC20 standard smart contract and XRG token are used on Ethereum. Their token system is determined to provide information about the external and internal conditions of the network, energy consumption, and production, and ownership of the produced energy [117].

3.3.3. Tennet (Netherlands & Germany)

In 2017, a TSO (Transmission system operator) is made by TenneT, jointly collaborating with frontman Germany and Netherland, for European electricity. TenneT jointly with others like IBM, Venderbron, etc. developed a system to manage the electric grids between the two countries, Netherlands and Germany. It was the initiative to enable the facility for decentralized energy sources to manage the electric grid. This kind of initiative may also facilitate future smart grid communication technologies according to European standardization [112].

3.3.4. MotionWrek(Germany)

MotionWrek, an energy BCn company founded in 2017. It is basically a Germany-based company that is working on building electromobility solutions on the basis of shared and green electricity, and digital technology like BCn. It mainly works for managing EV charging energy transactions. Their first project was ‘Share & Charge’. Firstly, they want to regionally connect the emobolists to help each other and then collaborate with the big companies on the same platform to increase the scalability of the charging facility [127]. Through the Share & Charge app, the charging point operators connect the charging infrastructure with the users who needs their EVs to be charged. It basically provides a network of EV charging, open mobility systems, and roaming solutions. They have projects including P2P Germany, P2P California, UK Pilot, Oslo to Rome, and all are for EV charging [111].

3.3.5. Alliander and spectra(Netherlands)

Alliander is a Dutch energy network company. It is working on developing a P2P energy-sharing platform based on BCn De Ceuvel in Amsterdam. This project is named Jouliette. This project is developed to complete transactions quickly and efficiently [128]. In 2018, the system developed by Alliander including RE was able to give service to over one million households in its area. A huge number of businesses and households started injecting renewable energy in the grids. It increased over 40% in the year between 2017 and 2018 [129]. For this increasing tendency of the system to be more and more connective, it was necessary to collaborate with the central authority. So, one of the partners collaborating with a company for smart energy services called Spectral Energy developed Jouliette. A token system based on BCn technology will help the local people to share and manage the locally produced RE. This project showed a high potential that BCn could be used very effectively in P2P energy trading. In the second phase, in 2018 Jouliette focused on analyzing the result by spreading their token system to integrate this with the daily activities of the people in the De Ceuvel community [130].

Table 4
Blockchain projects span the electricity sector.

Sector of SGES	Potential benefit	Platform	Year of implementing BCn	Country
Energy trading	-Cost minimization	-Enerchain (Ponton) [118] -Interbit (BTL) [119]	2018 2017	Germany Canada
Energy market	-Payment processing cost reduction -Billing transparency -More options of energy supply	-Drift [57] -Grid+ [120]	2016 2018	USA
P2P marketplace	-Development of DER economics -More options of energy supply -Reduce load on transmission network	-Brooklyn Microgrid project (LO3 Energy) [121] -Jouliette(Alliander and Spectral) [122]	2017 2018	USA Netherland
Supply and demand management	-Supply and demand chain balancing	-TenneT [123] -Electron [118]	2018 2016	Netherland
Charging EVs	-Charging and discharging coordination of EVs	-Share & Charge (MotionWerk)[63] -eMotorWerks [105]	2016 2017	UK USA
Network monitoring and security	-Enhancing network management and security	-Keyless Signature Infrastructure (Guardtime) [124]	2008	Estonia
RE market	Efficiency and transparency improvement	-SolarCoin [125] -Ideo CoLab [126]	2015 2018	Andorra USA

3.4. Critical requisites for next-generation blockchain in SGES

The reliability of the SGES depends on the feature of availability, security, controlling and handling capability of information, and communication of its own. Among the features, the confidentiality of the personal data, the integrity of the transmitted, and the availability of the stored data are the three most important ones [78]. When the amount of data and information are transferred through modern devices like computer networks in order to make decisions or transaction confirmation, there arises vulnerability even after applying the existing BCn technology. The vulnerability mainly arises because of the increasing integration of the many modern IoT elements to the SGES which communicate and transfer their data using the internet. Therefore, in the case of SGES, the following issues are needed to be considered to form the future issue of BCn technology.

3.4.1. Scalability issues

With the present consensus mechanisms available such as PoW, and PoS, it takes a lot of time and effort to complete a transaction or to create a block. They also consumed a lot of power as the number of miners participating in the mining is increasing gradually. As a result, the number of nodes or consumers increases in the SGES [131]. So, to maintain its performance with the increasing number of consumers, it will have to keep within certain limits. Here, the scalability of the SGES may be hindered [108]. Moreover, by the present BCn mechanism, the expansion of the scale of the SGES there lies a disguised centralization as the mining power can be centralized by a single entity or a few numbers of entities that demotivates the miners of other areas to take part in the mining. Also, the present BCn-enabled system has very little interoperability and heterogeneity facilities that is hindering the quick expansion of SGES. This is the case where we need to revise the modeling of the existing BCn network for increasing the scalability largely.

3.4.2. Cost inefficiency

The huge mining companies already use very high configurations and take control of the systems. With the present BCn technology, there is needed a very high configuration hardware system to get the mining validity to compete with them which can be resolved by using the advanced consensus mechanism. Also because of the high amount of power consumption [132] and involvement of the 3rd party, an additional form of currency is required. These can be managed by integrating the additional or improved features in the current form of BCn technology like IBSM, inter SC algorithm and so on which makes SGES to be more cost-effective.

3.4.3. Availability issues

Here, the term availability refers to the assurance of accessing the data or information timely, and the retained of reliable data. The absence of availability could interrupt the supply of energy as well as the management of the grids. When the information of the contacts increases in the SGES landscape, it hampers the data transmission and disrupts the authorized access to the system [20]. So, it is mandatory to ensure the appropriate security to maintain maximum availability. With the present BCn, causing a high degree of third-party involvement, the data-accessing process in SGES is slower, difficult, and unreliable which demands revising the modeling of the existing BCn.

3.4.4. Authentication issues

Modern SGES consist of many intelligent systems and devices. They are mostly electrical and electronic devices and systems. However, to control, monitor, and, maintain the system properly, proper identification of the devices and the owner of them are mandatory. By the proper authentication of the devices, the access to the resources of the system by outsiders can be identified. In the present BCn-enabled SGES authentication, it is important to give access to legal nodes or persons only. At the time of the authentication process, attackers may access the personal information of that user and hamper the protocol of the network [107,133]. It can be solved by a process in which the users have to go through some authentication processes like solving some cryptographic functions or encryption processes etc. Moreover, it can be prevented by developing new and unique encryption techniques so that it cannot be guessed or cracked easily.

3.4.5. Heterogeneity and interoperability issues

BCn technology implemented SGES has a little amount of interoperability and heterogeneity facility. In the case of inter-chain communications, one person is needed to trust and depend on the third-party authority. Also, it is only possible to trade an amount of energy only. There is no facility to execute inter-chain smart contract execution to increase the inter-chain operations as well as the interoperability [20]. To solve these issues and facilitate the features, it is necessary to modify the current version of the BCn in the SGES terminology.

3.4.6. Price standardization issues

In the SGES system, there is no price standardization process applied to the current form of BCn technology. The BCn technology at present has no such facility. As a result, there can be a conflict or syndicate in the time prize standardization during energy trading. Also, the role of third-party may arise here which can lead to a price hike. Also, mismanagement can happen in case of the proper price of the supplied amount of energy. Here, the next-generation BCn can play an important role by establishing real-time price standardization facilities depending on the facilities provided by the particular SGES.

3.4.7. Security issues

The present BCn technology involved in the SGES has mechanisms that involve disguising the centralization and dependency on third parties. This mechanism arises security issues in the SGES. Because of the centralization of the mining power, the chances of a 51% attack are high in there. The chances of data mutability, fake trading, and double spending can also be increased [107]. Also, because of the dependency on the 3rd party authority in various operations like inter-chain operation, smart contract execution, price standardization, etc., it puts the system under threat of security breach. There can be happened different types of attacks like MITM. The third-party authority or hackers gets the loophole to attack or control the system during the operations. So, it is necessary to minimize these issues.

4. Towards next-generation BCn technology in SGES: Opportunities and roadmap

4.1. Add-on features in BCn technology

As we have seen before, the present scenario BCn network is one of the most popular emerging technology due to its exclusive features such as decentralized, secured, reliable, trustworthy transparent, etc. But as an emerging technology, it is not totally flawless and has many areas to improve. This technology is not fully secured or decentralized yet because of the centralization of the mining power. For example, in the hash generation power of the 20 pools of different geographical locations for Bitcoin mining, it is found that almost 65% of the hash power is distributed in China, 10% in Malta, 3% in the USA and the Czech Republic, and so on. From this study, it is estimated that 75% of the network hash rate is controlled by the miners of the two areas only in the case of bitcoins. It still has the threat of the 51% attack in which the leading minors can manipulate or temper the data in the BCn. The mentioned issues can be resolved by incorporating the following features in BCn network.

4.1.1. Smart consensus mechanism

There are a few consensus mechanisms available now such as PoW, PoS, DPoS, PoT, PoH, CW-PoW, etc. Among them, the most widely used mechanisms in the public BCs are PoW and the PoS. The problem with the PoW is all the miner nodes participate in the mining at a time for a block, resulting in the power or energy consumption becoming very high [134]. It takes almost 10 min to validate and complete any transaction which is very slow compared to many existing digital transaction systems. Again, in the case of PoS, the higher the stake number becomes the higher possibility of minor getting permission to create a hash [135]. In this way, the rich miners become richer. Though there is a solution by providing another criterion “Age of the Stake”. However, the possibility of centralization is much higher for AoS. In this scenario, an effective future consensus mechanism can be a Proof of Lowness (POL).

Here, the lowness means the lowness of the traffic of the minors interested in any area. When any sets of data will be released to create a block, all the minors present in the chain, who will be interested to create a hash, will respond. Then the system will analyze in which area or zone the minimum number of interested minors is presented. It will allow the minors in that particular area or number of areas where the minimum number of minors are present. There will be a preset limit for each chain to participate in a minimum and a maximum number of minors that can participate in a session of mining. According to that one or, more than one areas can be selected in which the appropriate number of members will be available. As a result, the centralization of the mining power will be compensated. The chance of dominating and 51% attack will also be reduced. There will be no chance for the riches to become richer. Also, as the number of minors competing will be less so the consumption of power will also be less. In addition to this, as all the minors are not competing at the same time for mining (only the miners of the specific areas will be engaged in mining at a time), the miners of the other areas will be available and they will take part in the inter operations like in-system miner based agenting, and inter-chain smart contract algorithm.

4.1.2. Intelligent storage management system

The BCn currently uses mainly two types of storage management systems. On-chain and off-chain storage management system (SMS). On-chain SMS is more transparent, irreversible, and immutable. But all the data storing, transaction processing and upgrading will be directly live on the main chain. As the storage of each node is limited, doing all the operations at a time becomes difficult and slow. Off-chain SMS is off the public storage chain. Here, only the hash number of the files, resources, data, and transactions will be shown on the main public chain or on the on-chain storage. The data in the off-chain is large and non-transactional data, which is very large in size. Off-chain SMS is faster, cheaper, and more private. However, it stays only the fingerprint or the track of the transaction but the detailed data availability is not present. So, if any data is missing, the computation becomes impossible to be performed. When giving access to the consortium member to the off-chain data to provide detailed information related to the transaction, it is possible that confidential or private data gets exposed accidentally. Here, an intelligent storage management system can be considered to solve the above issue which basically uses the mechanism of the off-chain storage mechanism. There will be an additional individual read-only storage with a large capacity for each BCn network with the facility of a query language. This additional dynamic storage layer (DSL) will also have the functionality of first in first out (FIFO). It contains a section to enforce the algorithm for managing the smart contract (SC) which will further help in case of expanding heterogeneity or interoperability of the BCn.

4.1.3. Enhanced interoperability and heterogeneity

To increase the scalability and wide use of a decentralized ledger system, it is not possible for a single developed BCn alone. There is a requirement for multiple BCn to contribute together and to do so, there should be enough facility and flexibility to intercommunicate and interoperate. The interoperability and heterogeneity are still available in the present scenario [136]. However, most of the technologies facilitating these two features of the BCn include a third-party entity or organization-developed mechanisms such as Loom, Horizon uses sidechain, Coinbase, Kraken uses notary sidechain, Hyperledger, cactus use BCn migrators, etc [137]. Another issue is to asset transfer by using the token technology which avoids the policy of a smart contract on one BCn if a condition is present in another BCn. There is a lack of standardization of transactions in case of enforcing a smart contract on separate BCn. So, to enhance the two mentioned facilities the following mechanisms may have to be included in the future.

(i) Inter-chain SC algorithm: Most of the technologies are only used for asset transfer by token technology. However, there is no way to enforce an SC on one BCn if a condition is present in another BCn. During the asset transfer which currency does not have any SC system such as Bitcoin just the amount, anyone pays for is frozen on an SC to symbolize which person has paid for that amount and owns it. So, to facilitate the feature that the enforcing of an SC not only in the chain but also from another chain. Let us take an example to understand properly. Consider there is a person in Ethereum network who wants to store his data in another network of Polygon. Because per unit space the fee for storage is lesser in Polygon than in Ethereum. When the node in the Ethereum network crates, signs of SC on the DSL of the Polygon are provided. The DSL will invite a certain number of miners to check its validity and the possibility of completion of the condition.

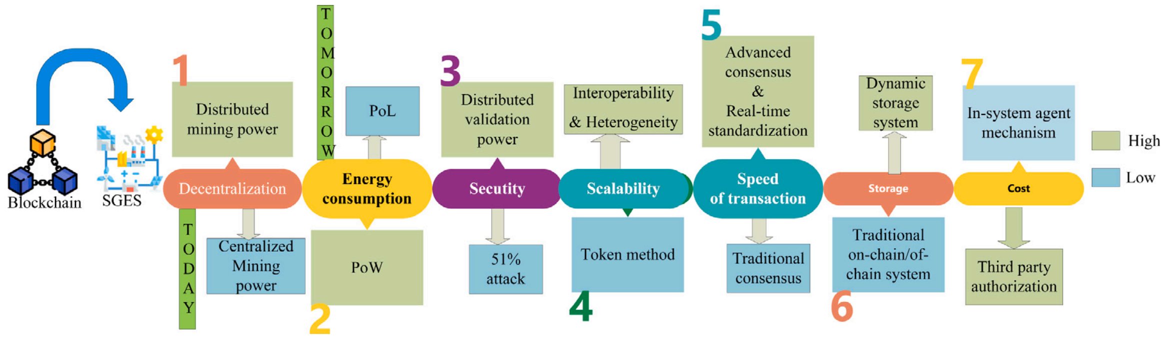

Fig. 10. Present and next-generation BCn enabled SGES.

Then, the result is shown to the consumer. If the data is valid, the transaction is proceeded and the miner gets a reward from the fee that the consumer will give for checking. If not, then the fake data provider will be penalized and have to give a fine from which the miner will be paid.

(ii) Instant standardization protocol: Every network uses a specific mechanism so that the traded prices stay the same and required standardization. According to that standardization, the exchange rate, and transaction fee will be determined. But just like any other existing monetary system if any particular cryptocurrency is set to be the only standard value, there will be a raise in the centralization of the network again. The BCn that holds the currency will dominate the others. Also, there will be the necessity for a central authority to manage the value of every currency in the dominant currency that will join the BCn system. In this case, the central authority can be compromised or they can be biased. As a result, proper evaluation of a currency may be hindered. To solve this problem in the future BCn and to facilitate interoperability there will be a mechanism or algorithm to instantly compare the degree of security, speed, scalability, transparency, and privacy between two or more networks that are involved in any particular inter-chain communication. The network which will have the highest degree for that particular operation, the currency of that BCn will be the standard currency and the transaction, payments, and exchanges will be on that currency. This approach firstly avoids centralization as well as the inclusion of the 3rd party. Secondly, BCn will be motivated to get the incentive and compete for improving their network performance degree.

(iii) In-system bridge mechanism(IBSM): This bridge is a connection that allows the nodes to transfer tokens or other data from one chain or network to another. It allows the ability to interact with another chain via a token. Tokens are the virtual version of the assets built on another BCn with different coins or currency. So, in any other network of BCn, anyone may have the currency of his own network in the form of tokens. The binance bridge, xPollinate, Matic bridge, and Multi-chain are some of the widely used bridge mechanisms currently applied in the inter-chain communication of the different BCns. But as mentioned before they are mostly developed and maintained by some organizations or entities. So, they are providing the inter-communication protocol but the controlling power is still staying in their hands which becomes the network centralized anyway. Thus, the chances of compromising of both the BCs' security, privacy, and transaction validity are increasing. Here, the developed algorithms and technologies in future BCns will rely upon the totally self-dependent ISBM. In this protocol, the main features may have 'In system miner based agenting' and 'ID based recognition of the nodes and chains'.

- *In-system miner based agenting:* This feature refers that the miners present in the systems connecting or inter-communicating will play the role of the 3rd party bridge-mechanism providers. When any transaction between two nodes of different BCns will be needed, the consumer will send a request to its server to trade the cryptocurrency of his BCn. The role of the in-chain miners' role will come into play. After the completion of the transaction, the miners on both chains will be rewarded by the transaction fee as an incentive. By using the protocol, the 3rd party interaction and domination may have to be removed.
- *ID-based recognition of the nodes and chains:* The availability and scalability of the BCns are going to be very high in the future due to the spreading of the internet. There will be a lot of BCn currencies available. Each one having specific advantages, security, reliability, fees for different activities, etc., may create limitations for another BCn. So, rather than having the name of the Chain as there may have pre-assigned some value or number to denote any specific network. We know at present, each node contains some hash value as its digital signature. Here, a number of bits will be assigned totally fixed for a definite BCn. It will be the unique ID of that definite BCn network. As the ID of the network will be globalized there will not be any doubt about the existence of that network. It will also be easier and quicker for the miner agent to work more accurately and precisely to validate and complete any transaction.

4.2. Opportunities of next-generation BCn for SGES

By considering the advanced feature of the next-generation BCn technology, we can overcome the difficulties that appear in the present BCn technology framework. A comparative analysis between present and future BCn has been presented in Fig. 10. The improved features of the next-generation BCn framework may offer the following benefits in the SGES landscape.

4.2.1. Increased scalability

Scalability is a big issue for the BCn-enabled SEGS. In the next generation BCn technology, there may exist an improved consensus mechanism called PoL. By implementing this consensus mechanism, the BCn networks can perform their transaction with less amount of power. It takes less time to validate a transaction and avoids to arise new problems even in the case of an increasing number of nodes or consumers. Also, the centralization of the mining power and disguised centralization of the system can be eliminated. The miners of different areas will be incentives to participate in the mining. As a result, more SGES communications will be facilitated to make more transactions.

4.2.2. Cost minimization

As the mining, and transaction processes become faster and the involvement of power-consuming hardware also gets reduced, the cost of the next-generation BCn framework may be minimized than the existing BCn framework. Also, the third-party involvement in all the cases will be removed and their payments also will be eliminated from the transaction costs. This will also significantly minimize the overall cost of next-generation BCn in the context of SGES.

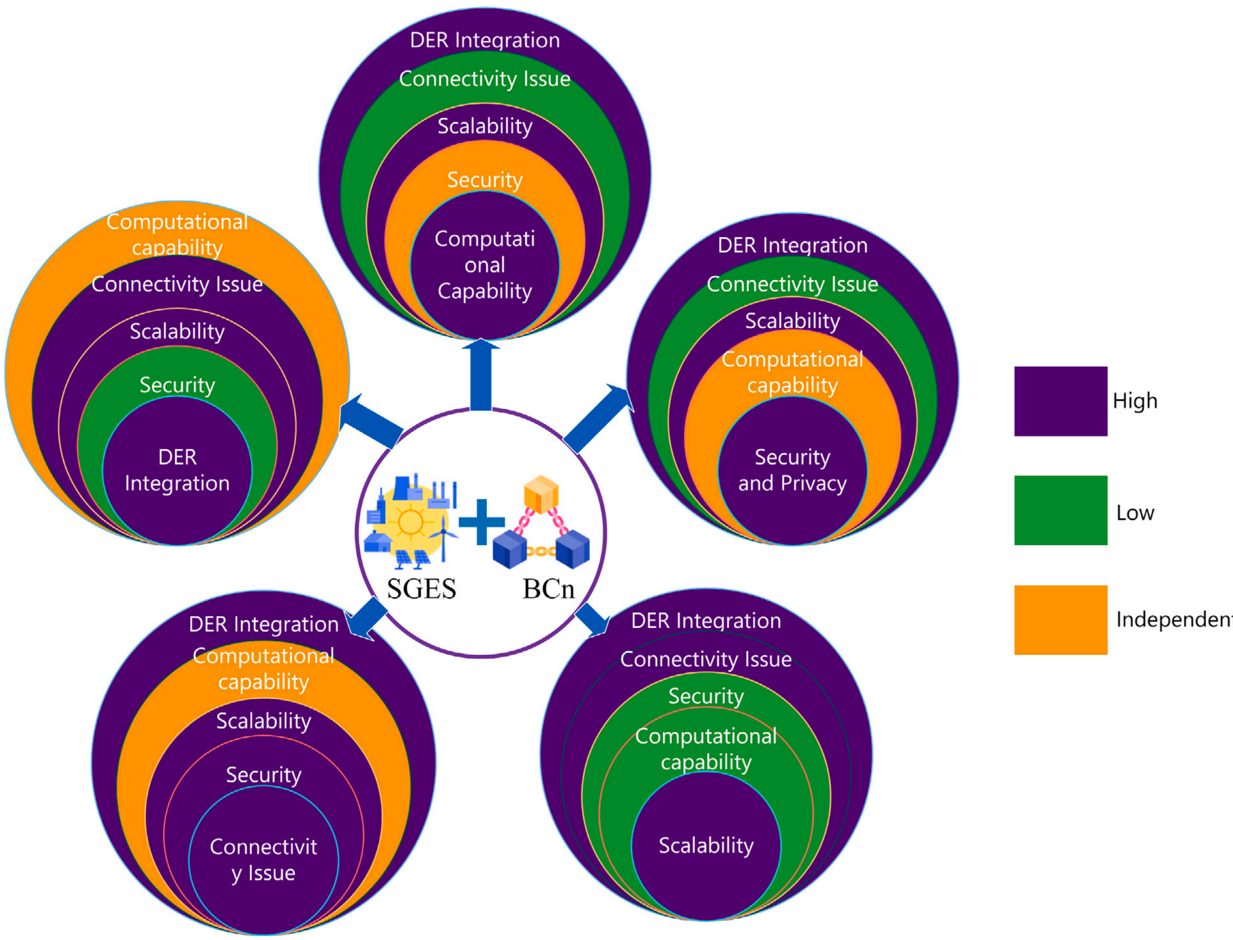

Fig. 11. Integration challenges of BCn in SGES.

4.2.3. Advanced availability

Availability refers to the assurance of accessing the data or information timely, and that reliability of the data is retained. Because of using the intelligent storage management system, any data exchange and access becomes quite fast and reliable. It requires to consume less computation power to access data timely as the transaction cost, validation cost gets reduced too. As a result, anyone on the network can access the data quickly.

4.2.4. Real-time price standardization

In the next-generation BCn, the feature instant standardization protocol may facilitate real-time price standardization for any power transaction. There may have no need for any third-party agent involved to set the price in any transaction. The price of any grid will be set automatically by the system itself according to the power quality, data security, speed of transaction, transparency, privacy, and grid management system of that grid. The higher degree of these parameters of any grid requires a high level of price.

4.2.5. Advanced security

With the use of an advanced consensus algorithm in the next-generation BCn framework, the centralization of the mining power may have to be eliminated. As a result, the chance of 51% attack will be decreased significantly and data manipulation or duplication may not be possible anymore. The chances of fake trading and double spending will be lowered which increases the security of BCn by enhancing the authentication capability of any transaction. Thus, the security breach of the system ledger and algorithm will stay at a lower risk than in the present scenario.

4.3. Integration challenges

The integration of BCn in the SGES provides advantages to all the stakeholders via immutability, anonymity, trustworthiness, and decentralized nature. Nonetheless, the challenges are negotiated here that have not gathered sufficient research potentiality in this context. Consequently, this study also discusses on integration challenges of the next-generation BCn framework in the SGES technology.

- The stability of the electricity grid is affected by the BCn and SC-based execution for vast-scale integration of distributed energy resources(DERs) that may further create threats for large scalability issues.
- It is a big challenge for BCn-integrated SGES to ensure reliability, low latency, and security of communication via the utilization of low bandwidth. To optimize these performances associated with available low bandwidth is a challenging task.
- BCn might be exposed to security attacks that contain the discharge of public and private keys that lead to the revealing of sensitive information, and the risk of dual spending. This can be further classified as manipulation-based, service-based, and identity-based attacks.
- SC might include bugs in its solely workable codes and security point which may have to be leveraged by attackers to hamper the entire system [106].
- Quantum resilience is another term responsible for the security issue of BCn network. The emergence of quantum computers enabling high computational capabilities might crack the security keys of BCn network [138]. This kind of attack could expose the amount of energy consumption and pattern of energy trading.

- BCn application programming interface (API) includes complicacy and operability issues that may not be addressed for the successful execution of BCn-enabled SGES.

In Fig. 11, the challenges that arise at the time of integrating BCn are summarized. When the DER integration increases, the security of the system gets reduced. On the other hand, the scalability and connectivity issues are increased. The only left criteria have no effect on the increasing DER integration. Similarly, if the connectivity issues of the system are not taken under concern i.e. the issues get increased it gives all the other parameters flexibility to increase except for computational capability. Connectivity issues cannot affect it. In case of increasing the computational capability of the system, it reduces connectivity issues at some level. The other two sections scalability and DER integration are privileged with the increases of computational capability. The left one security and privacy are not affected by computational capability. Subsequently, with the high security and privacy of the system, the DER integration and the scalability of the system also become high. On the contrary, the connectivity issues are reduced and become low. Like the previous relation, security and privacy do not affect the computational capability of the system. Finally, the system with a scalability capability will have the facility of high DER integration but have to deal with the problems of the high amount of connectivity issues, low security, and privacy, and low computational capability.

5. Future research directions

In this paper, it is discussed how next-generation BCn can be utilized to adapt SGES for rapidly changing digital technology. Nevertheless, there are still some scopes to work with.

5.1. Scope of AI technology

According to the experience gathered from collected data, AI technology can be utilized to provide predictive analysis [139]. Smart contracts empowered by AI can uplift the grids to manage and identify malicious functions and P2P transactions. Blockchain-based smart contracts that contain AI models can conduct transactions, such as stock purchases, reorders, payments, and dispute resolution, as well as propose which delivery method is the most environmentally friendly and can settle disputes. The AI/machine learning (ML) dependent predictive analysis may have to be applied via SCs to adjust the variation between the demand and supply of energy. Thus, Blockchain-based SGES networks will benefit from a new level of intelligence because of the amazing speed and ability of AI to read, comprehend, and correlate data in great detail. In this regard, the implementation of AI in the BCn smart contracts architecture may work as the ‘brain’ to attain a fully self-operated and decentralized framework [140]. This process would let the incorporation of additional input sources at any power or energy range level without influencing the stability of the SGES.

5.2. Scope of network slicing

Network slicing can be considered to solve connectivity issues. In this regard, the 5G network has to be divided into logically isolated networks prepared for several network operations together with distinct service level agreements (SLAs) [141]. The 5G network slicing would provide regulation of the distribution network, smart data management, and supervision of IoT-enabled devices for the SGES. The BCn network with smart contracts can be applied to establish trust between the participants belonging to separate network slices [142–144]. Again, the 6G wireless technology has to be utilized to preserve the sensitivity of data and ensure the faultless connection of devices belonging to heterogeneous networks so that hefty progress of interconnection can be assured [145,146]. The collaboration of 6G technology with BCn scheme could eradicate the existing connectivity issues.

5.3. Scope of BCn trilemma

Blockchain trilemma in smart grid applications incorporates three entities: security, decentralization, and scalability. Due to insufficient resources, trilemma may become one solution that has been observed as a hindrance in present BCn executions. As the number of devices connected to the smart grid is increasing, the operation would be hampered and the outcome may suffer scalability issues. Again, ensuring proper security in the same system may hinder as the size of the network is increased. Similarly, in the current frameworks, it is still a huge challenge to make the system secure and enlarge it potentially. BCn trilemma has more research potential, which includes various challenges in gaining totally decentralized, self-governed, and self-resilient SGES [20]. Many more research works are required to be executed to accomplish security features as well as scalability features of BCn to obtain multi-domain smart grid applications.

5.4. Scope of BCn with communication technologies

As the amount of IoT devices connected with smart grid infrastructure is increasing, it is also required to uphold high computational capabilities for processing more transactions than ever before. Latency would cross the pre-determined level and obstruct the efficiency of the system. Steady and diminutive communication among connected devices has become a significant requisite in the execution of smart grids. Maximum employment of the bandwidth for the communication technology to fulfill all of the demands is an arduous task [147]. A large amount of connection and traffic handling can be facilitated by the integration of BCn with improved telecommunication technologies, which would result in a self-governing smart grid infrastructure.

5.5. Scope of analysis

As BCn is still in its adolescence, a step-by-step analysis is required to formulate the standards and regulate the framework. By executing that analysis, BCn can be more useful to improve the SGES efficiency [88]. Such as BCn based systems rely upon the technology, not on a third-party intermediary of a centralized topology. In the latter case, there would be a responsible authority for any malfunction or misconduct observed within the system which is absent in blockchain-based systems. There should be something added so that people can connect with the system with their trust. Also, critical regulatory changes are expected in the SGES to facilitate wholesale as well as P2P energy trading. However, revealing transaction patterns leads to disclosing behavioral and habitual information. This would reveal user identities through compromised pseudo-anonymity and disclose energy consumption and trading patterns. Again, seamless interoperability of the system is still not achieved up to the mark. It is necessary to formulate standards and reliable communication protocols for the information exchange of the BCn-based SGES.

6. Conclusion

The rapidly increasing demand due to the fourth industrial energy revolution is going to be addressed through the employment of an advanced smart grid energy system. In this article, a study of more evolved blockchain technology can be referred to as next-generation blockchain, to mitigate the persisting challenges and optimize P2P energy trading, grid automation, and other operations are presented. Firstly, the existing blockchain with distributed ledger technology, impressive features, policies, and core technologies are discussed. Then, the key technology being used for the smart grid energy system, ongoing trends of blockchain in the smart grid energy system and critical issues like interoperability and heterogeneity to be addressed through next-generation blockchain in the smart grid energy system are presented. Again, the add-on features of blockchain technology, opportunities for next-generation blockchain in the advanced smart grid energy system, and integration challenges after utilizing next-generation blockchain in the smart grid energy system are analyzed. Finally, the directions towards future research are outlined in order to mitigate the challenges by applying next-generation blockchain technology for the sustainable operation of the smart grid energy system with advanced digital technology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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