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TOPICAL REVIEW

Review on Energy Application Using Blockchain Technology With an Introductions in the Pricing Infrastructure

TARIQ AL-ABRI[1], AHMET ONEN[1,2], RASHID AL-ABRI[1,3], (Member, IEEE), ABDULNASIR HOSSEN[1,4], (Senior Member, IEEE), AMER AL-HINAI[1], (Senior Member, IEEE), JAESUNG JUNG[5], (Member, IEEE), AND TAHA SELIM USTUN[6], (Member, IEEE)

[1]Department of Electrical and Computer Engineering, College of Engineering, Sultan Qaboos University, Muscat 123, Oman
[2]Electrical and Electrical Enginering, Abdullah Gul University, Kayseri 38080, Turkey
[3]Sustainable Energy Research Center, Sultan Qaboos University, Muscat 123, Oman
[4]Communication and Information Research Center, Sultan Qaboos University, Muscat 123, Oman
[5]Department of Energy Systems Research, Ajou University, Suwon-si 16499, South Korea
[6]Fukushima Renewable Energy Institute, AIST (FREA), National Institute of Advanced Industrial Science and Technology (AIST), Koriyama 963-0298, Japan

Corresponding author: Jaesung Jung (jjung@ajou.ac.kr)

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ABSTRACT With the rapid transformation of the energy sector towards modern power systems represented by smart grids (SGs), microgrids (MG), and distributed generation, blockchain (BC) technology has shown the capability for solving security, privacy, and reliability challenges that hinder progress. Currently, the energy structure is forming a decentralized system that prioritizes customer satisfaction. BC technology undertakes power network stockholders in a secure energy market, transparent transactions, and fair competition and offers promising energy solutions. This paper is a comprehensive review of energy applications using BC integration. Firstly, we introduce the drivers of BC leverage that make it a potentially important component of the power network. Following that, we provide background information on BC and its application in areas other than the energy sector. Subsequently, we discuss studies and sort potential energy applications from various recent papers and surveys that have already adopted BC technology in the energy sector. Then, we summarize the pricing infrastructure for applying BC in the energy sector and identify the requirements to build it. Finally, energy security and privacy challenges based on BC are highlighted, along with potential drawbacks and concerns related to the pricing infrastructure.

INDEX TERMS Blockchain, smart grid, IoT, smart contract, microgrid, AI, security, privacy.

NOMENCLATURE

AI	Artificial intelligence
BC	Blockchain
DG	Distribution generation
DLT	Distributed ledger technology
DRM	Demand response management
DSO	distributed system operator
EV	Electrical vehicle
G2V	Grid to vehicle
IoT	Internet of things
MG	Microgrids
P2P	Peer-to-Peer
PBFT	Practical Byzantine Fault Tolerance
PoS	Proof of stack
PoW	Proof of work
PV	Photovoltaic
RES	Renewable energy sources
SC	Smart contract
SG	Smart grid
SP	Service provider
V2G	Vehicle to grid

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I. INTRODUCTION

The global trend toward net-zero emission targets has increased drastically, highlighting the need to modify energy production and consumption behaviors [1]. This trend concerns using renewable power as new power sources and overcoming the obstacles that technically and economically inhibit the development of the energy sector. Smart grids (SGs) are an energy network upgrade with an intelligent metering infrastructure that operates by acquiring and analyzing huge system data from various technological electronics sensing devices [2]. Despite the crucial role of the internet of things (IoT) in SG, coordination between SG devices through public communication leads to security and privacy issues due to vulnerability to cyber-attacks. Extensive data exchange by entering the IoT increases cybersecurity vulnerabilities (e.g., false data injection attacks) [3]. Threats in taxonomy, theft of service, and system security undermine system reliability and sustainability [4]. Moreover, the coming decades will likely witness a significant change in the distribution system configuration with continued growth in distributed generation (DG) capacity, thus transforming the grid into a decentralized system and deregulating the market. In deregulated electricity market is allowed to own the power plants and transmission lines by new participants other than utilities. The liberated electricity market will provide a new contractual peer-to-peer (P2P) trading base between the agents in the deregulated power structure [5]. A deregulated market will redefine the trading scheme through simultaneous negotiation over price and energy, with the emergence of prosumer customers who have renewable energy sources (RES) and can either be consumers or producers of energy. The security and privacy of P2P energy transactions can be maintained by adapting to smart and safe contracts along with blocked transactive management infrastructure [6].

Prosumers play an important role in modern power trading [7]. They need to communicate with consumers and system operators to manage the supply and demand of the system through energy transactions and system requirements. All parties must be able to take part in this energy transaction. This can be done by using distributed ledger technology (DLT) based on the blockchain (BC) concept to issue smart contracts (SCs) to these parties [6].

BC is a promising technology that has drawn attention in different sectors by reformulating trust in a completely contrasting concept to that of centralized work systems (**Figure1**). Trust in centralized systems is reduced due to cyberattacks and the high exposure to potential manipulation [8]. In contrast, BC depends on a trustless network that enhances transparency, security, privacy, and traceability. The main features of BC are decentralization, immutability, auditability, and fault tolerance [9], [10] In BC, data (e.g., transactions) is validated by nodes without depending on a centralized entity. New data must be verified and approved after a decentralized consensus is reached, making manipulation impossible. The same principle is used to identify data leakages from replicas in the BC nodes [11]. BC can minimize human error and the need for manual intervention in the case of conflicting data. These features mean that BC will

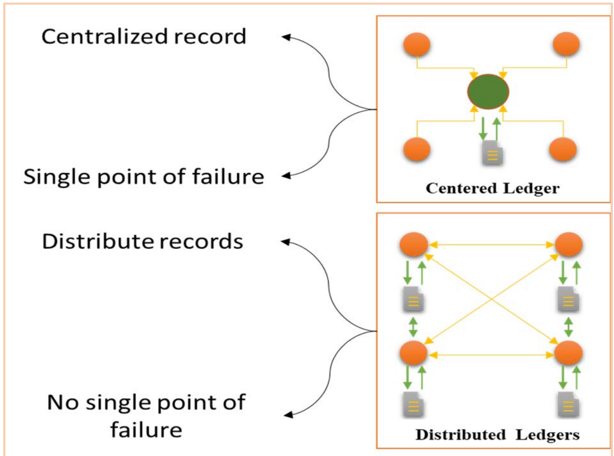

FIGURE 1. Centralized and decentralized system.

likely become part of the power system network and bring different benefits.

A past study presented the penetration impacts of a distributed rooftop photovoltaic (PV) system [12]. They mostly included issues related to power quality and stability. Moreover, the study suggested developing a demand-side management application to manage the load profile and optimize energy production. However, huge amounts of data are required to support demand-side management and conventional tools will not be sufficient to mitigate the impact of the PV system in the network unless sophisticated tools are developed to deal with the data. Similarly, an optimizing method was proposed to build a P2P exchange energy contract between prosumers and consumers under various renewable penetration rates by taking renewable sources and demand uncertainty into consideration [13]. Such a contract for P2P energy trading [14] has been found between electric vehicle (EV) owners [15]–[17], DG in microgrids (MGs) [18], and vehicle-to-grids (V2Gs). The purpose of P2P trading is to maximize social welfare and fairness with other power network considerations. This leads to an increase in the energy market as concerns about P2P energy contract privacy and security issues become a challenge. Therefore, decentralized P2P energy management without utility intervention is the most effective implementation for secure transactions among shared SCs in the BC node concepts [19]. These examples do not cover all existing challenges in energy sector applications for moving towards decentralization but aim to understand the need for BC integration in modern power networks. This paper will look more deeply at energy applications with BC integration in the following ways:

1) surveying recent studies that adopted BC in energy applications to determine the scope of work and use and the challenges of use,
2) identifying the links between BC technology and artificial intelligence (AI), and
3) summarizing the pricing infrastructure of applying BC in the energy sector.

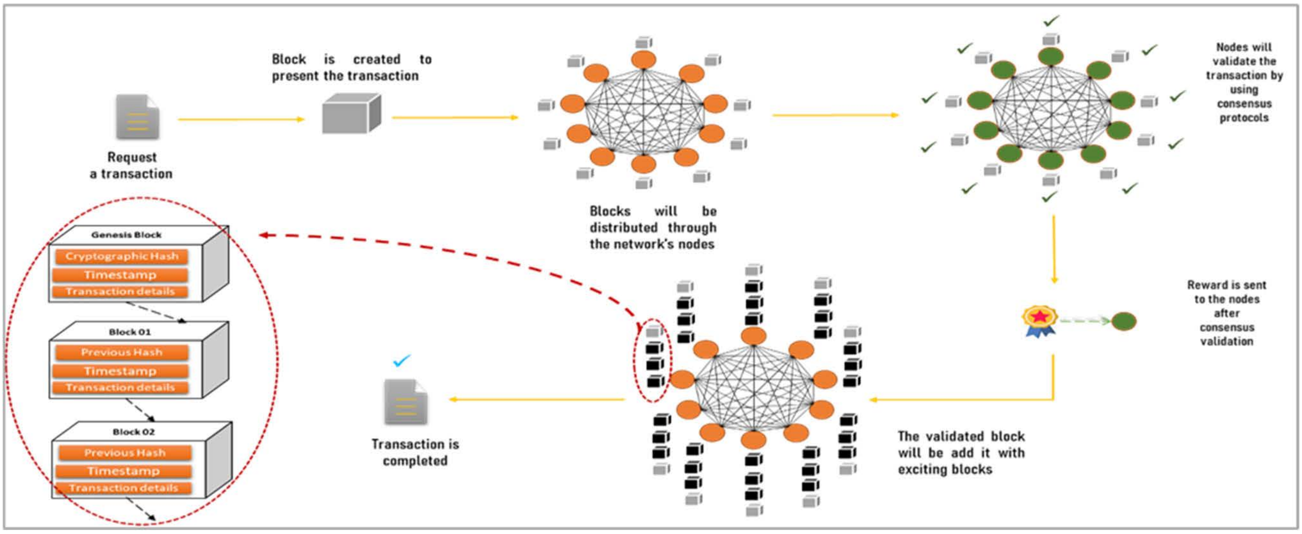

FIGURE 2. The concept of BC technology.

This study elaborates on energy applications with BC integration. Beginning with an explanation of the concept of BC technology and usage domain and followed by a review and study on BC for energy applications, this review will be a useful addition for studying the pricing infrastructure of applying BC to the energy sector and the role of BC in AI-based energy applications. This review explains the general global situation with regard to BC and highlights some security and privacy issues with using BC.

This paper is organized as follows. Section II: The Concept of BC; Section III: BC in the Energy Sector; Section IV: Pricing Infrastructure; Section V: Challenges and Concerns of BC in Energy Application; Section VI: Conclusion.

II. THE CONCEPT OF BC

BC is a decentralized system for digital data recording structures controlled through untrusted nodes (participant, anonymous mechanisms). This structure contains an append-only distributed ledger in the form of aggregated entries (e.g., transactions) within the series blocks [20]. The blocks are organized in order after an absolute agreement between the untrusting participants (special nodes, called miners) working with consensus protocols. Miners are working as auditors and they are getting paid for it. They are verifying the legitimacy of the transaction. The protocols follow systematic security and trust-solver algorithms [21]. The BC concept rapidly gained prominence following the publication of ''Bitcoin: A Peer-to-Peer Electronic Cash System'' [22] under the author's name *Satoshi Nakamoto,* the creator of Bitcoins [21], [23]. The accelerating interest in BC technology is due to the publicly accessible infrastructure without a centralized system known as opacity, fair access to resources, and data immutability and non-repudiation.

BC can be categorized into three major classes: public, private [21], [24], [25] and consortium [6], [9], [26], [27].

TABLE 1. Comparison among BC types: public, private and consortium based on [27]–[29].

Parameter	Public	Private	Consortium
Consensus process	Permissionless	Permissioned	Permissioned
Centralization	None	Full	Partial
participation	High	Low	Low
Identity of participants	Should be known	Are known Known	Are not known
Approving data by	Anyone can read and validate the ledgers	Restricted to pre-approved participants	Only pre-approved nodes can do
write	Anyone/Delegated	Pre-selected	Pre-selected
Read permission	Public	Public/Restricted	Pre-selected
Efficiency	Low	High	High
Immutability	Neary Tamper proof	Can be tempered	Can be tempered
Trust among participants	No	Yes	Yes
Finality (Stable Consensus)	No	Yes	Yes
Incentive	Yes	Not/Maybe	Not/Maybe
Platform's example	Bitcoin, Ethereum, EOS, Ripple, Sovrin	Hyperledger Fabric, Multichain,	Quoram, Corda, LTO, Holochain, Monet

Public BCs are open for any participant looking for a fully decentralized system. Bitcoin is an example of a public BC system. In contrast, private BC systems are close-ended, where permission to join the network is obtained through a consensus node governed by a centralized organization or authority. Quorum and Ethereum function as permissioned BC systems. Only a pre-selected group of trusted participants can join the consortium or federated BC systems, and a group of overseeing organizations must grant permission to operate a node. **Table1** compares between these classics based on different parameters. It can be noticed that each BC networks has its own features, advantages and disadvantages over one another. Therefore, they serve their purpose and find their solution for any particular problems differently.

Figure 2 illustrates the BC technology process. Any participants can create an authenticated transaction called block. Each block contains some data, hash of the block and hash

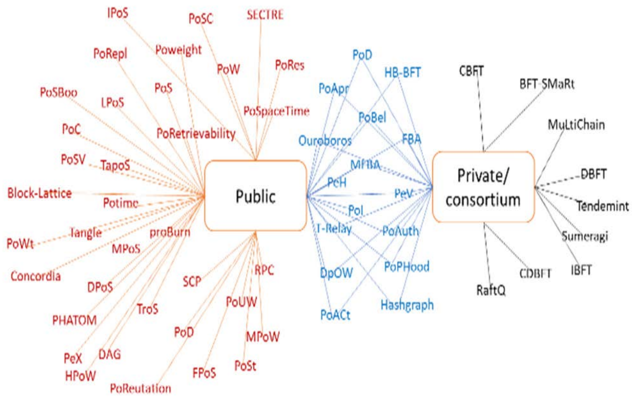

FIGURE 3. Consensus protocols in different BC types.

of the previous block. In fact, the hash identifies the block and all its details and it is always unique. Moreover, hashes are very important and useful when any one wants to detect changes to blocks. Each blocks have hash of the previous block except the first one which called genesis block. The data stored inside the blocks is depends on the BC type. The created block will be sent to every authorized participant to verify it through a computational process called consensus. After validating the block, it will be added to exciting blocks and finally, this update will be distributed across the network which announcing the end of the process.

A. CONSENSUS PROTOCOLS

The concept of BC technology eliminates the dependency on third-party intermediaries to apply transparency and ensure the veracity of the transactions. BC employs a consensus protocol with different algorithms to build trust in unsecured channels. Generally, a consensus protocol is the cornerstone of the performance and security measures of the BC network [30].

The main purpose of the consensus protocol is to obtain approval for a transaction from all the participants in the BC network. Therefore, all nodes must reject or accept transactions according to the contact of the block. Then, a consensus agreement is taken from all honest nodes to either accept or reject the transaction (liveness, termination). The accepted and validated blocks are stamped with a common sequence number and hash-chained to the previous blocks in chronological order (agreement, consistency) [31], [32].

Nakamoto [22] developed the most famous consensus protocol called proof of work (''PoW''), which is considered the main reason for the success of Bitcoins. Currently, there are various consensus protocols for BC applications, such as proof of stake (PoS), Practical Byzantine Fault Tolerance (PBFT), and Proof of Authority (PoA). **Figure 3** summarizes the consensus protocols used in relevant studies [21], [24], [27], [30], [33]–[39] which are linked -based on their functionality- in three different types: public, private and consortium.

There is no specific framework for classifying BC consensus protocols. The authors of [37] classified consensus protocols based on optimality, stability, efficiency, robustness, and persistence. In contrast, [27] classified the protocols based on their suitability for public or private BC and permissioned or permissionless BC, their efficiency, requirement of built-in incentive to compensate the participants, and the control of an organization on the network events. Additionally, other authors [30] compared the following parameters: applicability, basis for assigning accounting rights, degree of decentralization, accounting nodes, latency, throughput, fault tolerance rate, overhead, adversary tolerance, scalability, and security. Moreover, authors of another recent report [40] categorized consensus protocols based on ten parameters: BC type (private, public, consortium), scalability, attacks, adversary tolerance model, performance, communication model and complexity, energy consumption, mining and consensus category, and finality.

The BC consensus protocol should be selected based on a complete knowledge of their characteristics; otherwise, it can be a challenge, especially for BC developers, to work with poorly selected algorithms [37].

B. APPLICATION OF BC IN DIFFERENT DOMAINS

The application of BC has been extended to a wide range of domains. It can be implemented to solve many security, privacy, and data management issues in various sectors. The global success of Bitcoin applications widens the scope for BC technology to be utilized in several domains. The medical sector is a beneficiary of BC technology, primarily for healthcare. Additionally, the energy sector uses BC technology, especially in peer-to-peer energy trading, which coincides with using IoT technology in SGs. Moreover, BC simplifies, records, proves, and authenticates MG power transactions between peers through secure frameworks [41], [21]. In the government sector, the lack of trust in existing voting systems can be solved through BC by using distributed ledgers. Banking, finance trade, education sector, insurance, cyber security, and supply chain are other areas that may benefit from BC in terms of independence from third parties, enhanced security, flexibility and efficiency, robustness, cost reduction, reliability, and accessibility [25]. **Table 2** lists examples of domains where BC is applied.

III. BC IN THE ENERGY SECTOR

Owing to its transparency, decentralization, anonymity, and reliability, BC can solve many of the issues in the energy sector [63]. Currently, the energy sector is moving towards a decentralized system and a deregulated market structure. Technology enhancement leads to the introduction of new types of equipment and energy sources into power networks and allows bidirectional communication between the stockholders, thereby creating an SG. The increased integration of RES, storage systems, EV, DG, and MG in SG makes the traditional centralized power management model no longer attractive due to disadvantages in cost, security, control,

TABLE 2. A list of BC applications in different domains.

Ser.	Application	Example	Ref
1	SCs	Ethereum, SCs security in trading	[24],[42],[43],[44],[45],[46],[47]
2	Security trading and settlement	Secure Spectrum Trading in Cellular network, data trading certification	[24],[47],[48],[49]
3	Business	Supply chain, vehicle trading, finance, banking, cryptocurrency (Bitcoin),	[21],[24] ,[25],[50]
4	Services	E-voting, donation platform	[10, 11], [51],[52],[53]
5	Health care	Storing health information, managing patient data	[21],[25] ,[54],[55]
6	IoT	Chattel asset pledge financial, service, smart home IoT	[56],[57],[58]
7	Energy Industry	Energy trading, development of smart city, demand response management in vehicle-to-grid, grid management system	[25],[59],[60],[61]
8	Software	Auditable software validation system	[62]
9	communication	Infrastructure and resource sharing	[34]

energy trading, and energy management. Researchers have shown interest in using BC in the modern energy sector and they have addressed the issue of supply and demand in the complex energy market as the number of prosumers in the SG system increases. The following subsection reviews energy applications with integration of BC technology.

A. BC IN MG & SG

MGs make RES accessible on a large scale. However, operation control, energy management, and energy trading among the DG systems in the MG are concerns for the system operator. A large amount of information technology has been presented in MG to collect the necessary data for efficient grid monitoring and sustainable energy trading. Moreover, SGs support electricity market liberalization and focus on customer satisfaction. Hence, prosumers can use the energy produced from DG systems, such as RES, batteries, and EVs, and trade the surplus on MGs. The same trade is permissible between producers and consumers. This requires processing bidirectional energy trading without third-party interference but within a framework that allows for negotiation and bids based on supply and demand. In this case, BC has the properties to be used in open energy trading and market management [64]. Studies have focused on the use of BC in the energy market, P2P trading, energy management, EV, and CO_2 emission trading.

Masaud *et al.* [65] investigated the two-layer BC-based energy trading for many isolated MGs consisting of RES and power demand. BC technology was used in the second layer to achieve higher security by verifying, validating, and autonomously storing the executed contract from the first layer in accordance with two consensus protocols, pBFT and PoS. The blocks contained details of the seller and buyers, Kw price, traded energy amount, timestamp, previous block hash, and newly generated hash.

The authors of another study [59] presented an adaptive BC linked to a transactive energy market framework using a smart meter. Unlike conventional BC, the authors secured energy transactions in two bundled blocks: the first for the list of expected node energy transactions obtained from the market model solution and the second for the smart meters' real-time transactions. Therefore, the BC process matched the wallet billing rates of stockholders with the broadcast data of the smart meter. Blocks act as monetary funds and contain power committed, real-time data of smart meters (every 15 min), energy consumed, and updated funds at all nodes. Another study [66] used the DBFT protocol to achieve consensus for SCs between the EV owner and aggregator (monopolistic energy market operator). BC was used as a public audit to authenticate the seller and buyer account addresses, energy demand, related payment, transaction time, time stamp, and penalty price. Siano *et al.* [6] proposed a model that used the PoE protocol for P2P energy exchange between prosumers and customers in the local energy market [67] created a transactive energy model using BC with the PoEf protocol in smart meters of different SGs to ensure secure transactions and maintain a record of their final electrical consumption cost each period. In other studies, [68], [69], a P2P trading market model was presented for residential prosumers using a permissive BC system. This model reduced the interaction with the MG and optimized energy use efficiently and sustainably. A BC developed in another study [70] allowed each MG to exchange energy generation and consumption data in a secure and transparent power-trading framework. Then, based on the trade-off priority list between the interconnected MGs (commercial, hospital, residential, etc.), BC can be used by decision-makers to optimize problems in the internetwork. Employing BC reduces operation costs, increases system reliability, and improves system security. The same principle was introduced in the study by [71] but with a modified BC based on a directed acyclic graph. [72] proposed a novel methodology to remunerate users with utility tokens based on their contribution to fulfilling the requirements of load curve modification. In this method, the system operator invokes the SC and asks the demand response service to check the baseline of the user by reading all details registered in the BC. Shah *et al.* [73] presented a private BC that worked as a secure mediator between local MG controllers and utility operators to develop and solve optimum power flow problems in networks using recorded SC.

The P2P transactions were proposed for internal and multi-MGs based on double layer BC frameworks in order to provide decentralized trading market, transparency and trust between the nodes in the trading market [74].

Jindal *et al.* [75] proposed a BC scheme to validate transactions between network entities prior to energy trading. This study proved the ability and efficiency of BC in handling the demand response in SGs. In the study by Doan *et al.* [76] BC was used to generate an SC between MG prosumers by validating its P2P energy trading transaction. The BC used in the study by Wang *et al.* [77] was built based on the utility, prosumer, and aggregator of the SG to provide a trusted and decentralized framework for secure, transparent, and auditable data sharing. Furthermore, the data can be tracked to prove policy compliance. Another study [78] targeted small-scale prosumers for participative energy trading and proposed an adaptive BC model called SynergyChain. SynergyChain developed three different contracts, registration contracts, group contracts, and transaction contracts, for self-organized and leverage-grouped P2P trading. The aim of this model was to improve efficiency, decentralization, and profitability for prosumers.

B. BC APPLICATION IN EV

The number of EVs worldwide has increased rapidly [79]. Charging facilities are beginning to be distributed more widely to fulfill the charging/discharging requirements of EVs. As well as their transportation advantages, EVs can become part of the DG system, either sharing energy to the grid in V2G mode or consuming power from the grid in G2V mode. Therefore, EVs are an attractive platform for energy exchange. The characteristics of BC technology provide strong support for encouraging the use of EVs. The decentralized BC system provides competitive energy transactions for EVs in secure and private environments. Moreover, indirect benefits can be found when usage is increased, such as reductions in CO_2 emissions, ancillary services, and power loss reduction in the distribution system. Integration of BC with the EV system provides P2P energy trading, creates SC, exchanges data, secures communication, and provides other services.

Aggarwal *et al.* [80] proposed an energy trading scheme between EVs, charging stations, and the utilities during V2G mode. The P2P BC network was integrated to validate, verify, and execute distributed V2G transactions created by the utility center. Chen *et al.* [81] created a cryptography currency incentive based on a consortium BC system called EV coin. The block contained the ledger of the EV-coin transaction between EV drivers, utility, independent traders, renewable energy RE operators, and EV suppliers to optimize the power system and guide EV drivers to charge based on utility. The BC network based on the Hyperledger Fabric in the study by Li *et al.* [82] was designed for an EV P2P energy trading system with superconductive magnetic energy storage to obtain higher trading profits. The goal was to safely share the related electrical information between prosumers in terms of SC and implement it effectively in the market and pricing mechanisms and management systems.

C. BC AND DEMAND RESPONSE MANAGEMENT (DRM)

In modern power networks, with the presence of MG consisting of RES, power supply and demand need much control, especially with the uncertainty and diffusion of RES. Maintaining a match between supply and demand during power fluctuations requires active distribution system management that ensures privacy, security, fair energy trading, and a reliable network. BC can play a vital role in this and has demonstrated the ability to overcome DS challenges.

Aggarwal *et al.* [60] designed a consortium BC-based energy trading for DRM in a V2G environment for online energy transactions between EVs and service providers (SP) to ensure confidentiality and integrity preservation. The proposed model used price auction as a double auction mechanism to maximize social welfare, where BC functioned as an auctioneer to obtain the auction based on EV and SP bids. The BC technology used in a study by di Silvestre *et al.* [83] optimized the reactive power injection of the PV nodes. Each block can contain three energy transactions: prosumers' active power, energy losses, and reactive power. Then, a distributed system operator (DSO) reads the BC data to solve the reactive optimal power flow to regulate the voltages in each PV node. To overcome the security challenges in data aggregation and power dispatch in MGs, [84] used the PBFT consensus algorithm to create a BC for power data. The dispatchers then read the data, and automatically distributed dispatch is realized using the particle swarm optimization algorithm to determine the optimum solution and predict the distribution plan.

D. BC FOR PRIVACY-PRESERVING IN THE ENERGY SECTOR

The most important part of BC is the anonymous data exchange between users. Therefore, BC technology is a potential haven for the energy sector. Many researchers have proposed privacy-preserving BC using different methodologies.

Two protocols were used by Keshk *et al.* [85]; the proposed privacy-preserving frameworks use enhanced PoW (ePoW) to authenticate power system data, detecting potential manipulating attacks as first-level privacy and processing second-level privacy for inference attack protection. Baza *et al.* [84] proposed two privacy-preserving BC schemes. The first is to enable charging and payment between the EV drivers and charging stations using a private BC system. The charging station sends its bids, and then the EV driver will select the most suitable one. The second scheme enables energy trading between EVs (charging/discharging and trading V2V settings). A SC was built using a consortium BC to prevent privacy breaches in energy trading [86]. The integration of BC with a smart meter was proposed by Yang *et al.* [87]. Smart meters can share information in a decentralized, secure, and privacy-preserving platform. The model adopted two energy transactions: vertical and horizontal. Vertical transactions perform DRM by selling PV energy

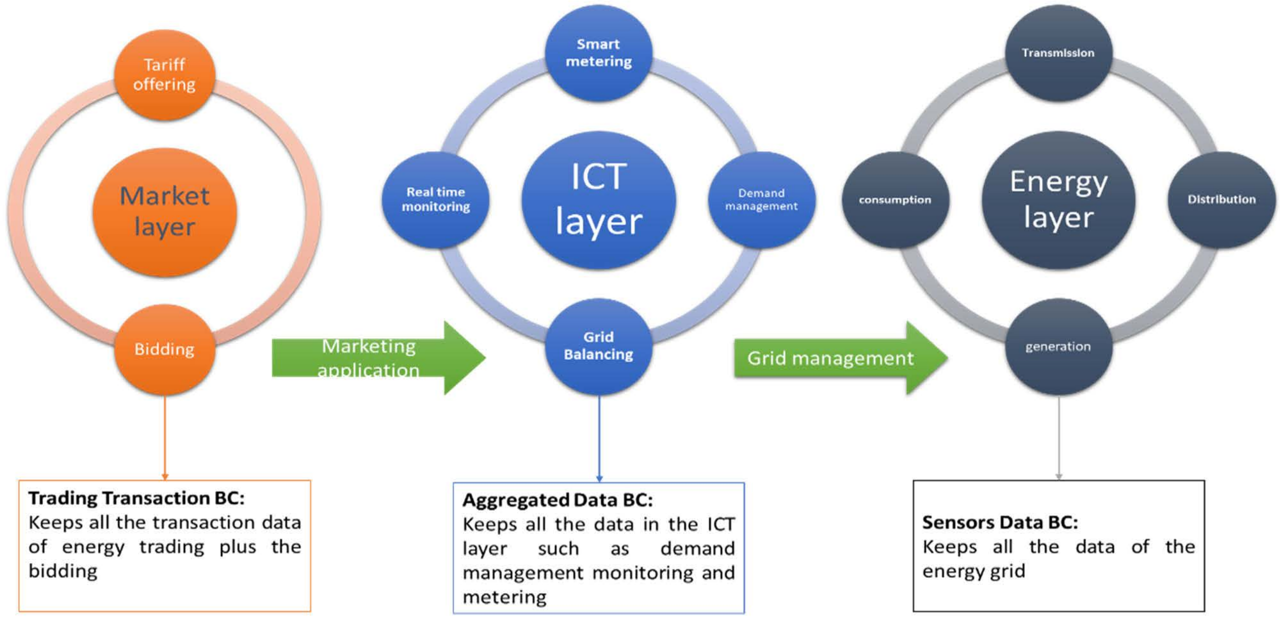

FIGURE 4. Categorization of BC in energy applications.

production to the grid, whereas horizontal transactions handle energy trading between the smart meters themselves.

BC application frameworks can be categorized into three working layers, as shown in **Figure 4** [87]. This study applied this categorization to the aforementioned energy applications (**Table 3**). Moreover, a general BC-layered architecture was proposed by Bhutta *et al.* [88], [89] to develop other distributed applications. This architecture consisted of an application layer (e.g., IoT, market security), contracts layer (e.g., algorithms and SCs), incentive layer (e.g., allocation mechanism), consensus protocols (e.g., POW, PoS), network layer (e.g., P2P network, verification mechanism), and data layers (e.g., data block, chain structure, and timestamp).

E. REVIEWS ON APPLICATION OF BC IN THE ENERGY SECTOR

Some energy applications of BC technology have been presented in past reviews and are summarized in**Table 4.** These reviews supported their content with several papers containing proposals for BC integration technology in energy networks. However, the common proposals to integrate BC in the energy sector were in the following applications: P2P Energy trading, SC, data exchange, power flow solution, DR management, privacy and security, data management, emission trading, emission reduction, energy market, and ancillary services (**Table 5**).

Most of the reviews mentioned in **Table 4** focused on energy applications. The following section summarizes the requirements for building a pricing infrastructure for the energy application of BC.

IV. PRICING INFRASTRUCTURE

The traditional centralized structure of the electric product market is based on huge cash flow investments in generation, transmission lines, and distribution. The return cycle of the investment is very long, followed by a heavily dependent cash-flow structure with a limited number of producers. The traditional structure is described as monopolistic. As explained earlier, BC technology encourages more small-scale power prosumers and more DGs units in the power network. This creates greater energy market competition. Nevertheless, the investment scale will be lower than that of the traditional market because most DGs substitute the cost of the transmission and distribution system expansion as well as the deferral of new capacity. **Figure 6** illustrates the differences between the traditional and decentralized market structures. **Figure 5 (a)** shows an extreme situation of the power manufacturer where P is the price of the electricity product, yield (power production capacity),D is the demand curve, q is the output of the power manufacturers with smallest efficiency scale. This represents that traditional market structure for power production accommodated a limited number of power producers as a result of huge minimum efficiency scale usage. In the other hand, **Figure 5 (b)** represents the corresponding distributed market's structure. As can be seen from latest graph, the encouragement of accommodating small-scale power prosumers and more DGs units (different products q1, q2, q3, q4) in the power network will have a direct influence in reduction energy price which caused to get competitive different market prices such as p1, p2 and so on. Price flexibility in the distribution market is greater than that in the traditional market, which leads to more customer stratification [101].

The pricing infrastructure for energy trading depends on many factors, including the cost of designing and developing related software and hardware. Furthermore, the cost of quality assurance and maintenance should be considered to ensure high performance and maintain the required testing

TABLE 3. BC categories based on the energy applications.

Sr.	Category	Ref.	Targeted User	Network	Type of BC	Protocol	Purpose of the BC
1	Market Money flow	[60]	EVs + Service Providers	Ethereum	Consortium	PoA	Improves transaction security and provides transparency in energy trading between EVs and the SPs
		[69]	Auctioneer + participants + utility	Ethereum	Consortium	-	P2P energy trading with SC. The SC calculates the market-clearing price and quantity of the respective market interval using a double auction and publishes it
		[75]	Residential homes + buildings + Industries + EVs	-	Public	PoW	Validates the transaction for energy trading
		[74]	Multi MGs	-	Consortium	-	Trading in the power market to realize transactions' transparency
		[82]	EVs + prosumers	Hyperledger Fabric	Consortium	-	P2P energy trading
		[76]	Prosumers	Hyperledger Fabric(python)	Private	-	Generates an SC between MG prosumers through validating their P2P energy trading transaction
		[86]	Prosumers	-	Consortium	-	Prevents privacy leakage without restricting energy trading between prosumers
		[87]	Prosumers	Ethereum	-	pBFT	Develops a privacy-preserving distributed algorithm to optimally manage the energy usage in parallel via the SC on the BC
		[78]	Prosumers + consumers	Python	Public/private	-	P2P Energy Trading to improve efficiency, decentralization, and profitability of the prosumers
		[68]	Prosumers + utility	Ethereum	Private	HLF	P2P energy trading with SC
		[67]	Prosumers	Python	Private	PoEf	Ensure security transactions and maintain their final electrical consumption cost in every period.
2	ICT Data flow	[65]	Prosumers + consumers	Python	Private	pBFT Modified PoS	Ensure high security by verifying, validating, and storing executed energy exchange contracts
		[59]	Customers + DG owners	Python	Consortium	PoW	A monetary fund
		[85]	Smart meter + power system	-	Public	ePoW	Authenticates data integrity and detects attacks
		[66]	EVs + aggregator	-	Private	DBFT	SC auditing
		[80]	EVs + charging station + utility	-	Public	PoW	Validates, verifies, and executes distributed V2G transactions created by the utility center.
		[81]	Utility+ EV drivers+ EV charging service providers + RE providers	-	Consortium	-	Enhances the guiding capability in the power network
		[70]	MG owners + consumers	-	-	-	Energy management
		[71]	Four MG owners (2 residential + hospital + commercial)	-	Private	-	Energy management
		[90]	EVs	Ganache/Ethereum	Private / public	PoS/PoW	Two privacies preserving BC schemes for EV energy trading
3	Energy flow	[83]	Prosumers + consumers+ DSO + MG operator	-	Private	-	Optimizes the injected reactive power
		[84]	Consumer + bookkeepers + Aggregator + smart meters	Ethereum.	Consortium	PBFT	Guarantees the correctness of aggregation results in a decentralized environment
		[72]	Smart meters	Hyperledger Fabric	Private	Gossip	Demand response remuneration programs
		[73]	MG controllers +	Ethereum	Private		Optimizes problem solver by using SC deployed on the BC
		[77]	Prosumers	-	Public	PoS&DPoS-BFT	A solution for secure and auditable private data sharing in SGs

TABLE 4. Review paper contributions.

Ref	Contribution
[91]	Provided proof that BC is a promising technology that can be implemented in the power sector. This paper presented many possible applications in SG and identified challenges and security issues
[92]	Discussed the pros and cons of the use of BC technology in various power system applications considering their features and provided matches between BC characteristics and power application requirements
[89]	Analyzed the contribution of countries, institutions, and individuals to BC and presented the status of BC research in the energy field
[93]	Analyzed the applicability of BC technology in SG 2.0
[63]	Represented BC applications in the energy sector and potential challenges
[94]	Compared digital and informational statistics on the roles of the countries, institutions, and journals to BC in the energy sector
[95]	Represented the applications of BC in smart cities
[96]	Reviewed BC in energy applications and cases and business opportunities for BC innovation
[97]	Determined the use of BC in energy application and demonstrated interframework for SC
[64]	Determined the role of BC in SG with challenges and direct future research avenues
[98]	Determined DSO-based requirements for potential BC applications in the energy sector
[99]	Focused on how BC can be used with RES
[100]	Proposed an analytical framework for P2P MG to identify the dimension of the implications for institutional development

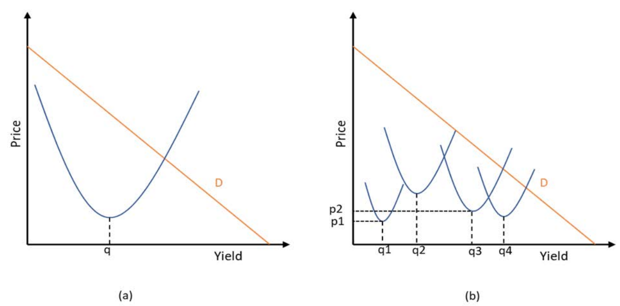

FIGURE 5. (a) The market structure of monopoly. (b) Distributed energy market structure.

TABLE 5. Uses of BC in energy applications from past studies.

Ref.	Energy application	Use of BC
[63]	Decentralized storage and control in the power grid	Data storage, decentralized grid and SG control, consumer data protection, demand-side management of grid
	P2P energy trading in SG	Different pricing mechanisms: market auction, distributed pricing, anonymously negotiating energy by price
	Electric vehicles	Solve fairness problems in direct charging exchange, privacy protection, enhance the security of energy trading, optimize model charging scheduling
	Carbon emission trading and green certificate	Create a secure platform to reduce CO_2 emission by tracking the emission quote of the power producers
[95]	SG	Energy trading, enhancement of stability and data Security, trading of the renewable energy
[96]	Energy industry	Metering/ billing and security, cryptocurrencies, tokens and investment, decentralized energy trading; green certificates and carbon trading; grid management; IoT, smart devices, automation and asset management, electric e-mobility, and general-purpose initiatives and consortia
[97]	SG	P2P energy trading, EV, MG operation, cyber-physical security
[64]	SG	Motivation of adoption BC and SG, BC for advanced metering infrastructure, decentralized energy trading & market, energy cyber physical system (CPS), EVs management, MG
[98]	SG +MG	Energy storage system, EV application, DER & MG, Energy market, DR, TSO/DSO interaction
[94]	Decentralized energy markets	Energy trading, decentralized energy generation and storage
	MG + SG	SC, smart meter, P2P, EV
	Energy internet	Energy solution, harvesting data from the advanced energy devices

and updating of the system. Next, the following graphs summarize some studies that proposed different philosophies and constraints to building pricing infrastructure.

Khattak *et al.* [102] proposed an adynamic price to allow energy trading between utilities, consumers, and prosumers via SCs validated by an intelligent BC. The price was

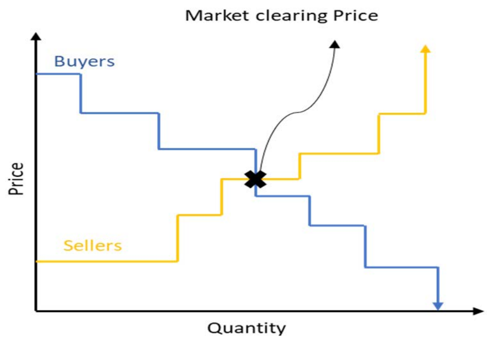

FIGURE 6. Double auction market clearing.

calculated based on the amount of electricity available for sale and is settled by the administrator through a bidding process based on the demand and supply of energy, depending on the modified time of the tariff presented as a BC coin. Similarly, another study [101] used the bidding process to set a uniform price. Intelligent controllers are used for placing demand and supply bids in the market. The participant will send their requests and offers in terms of SCs to clear the market using the BC. The transaction is not approved if there is an overload in one of the power system parameters. Therefore, the power flow module was integrated into the BC consensus process to ensure that both the market and price did not violate network constraints. The bids apply a double auction market, which stacks the supply bids in increasing order and the demand bids in decreasing order until both reached to the balance or clear point where both of them have the same quantity. This point called market clearing price (**Figure 6**).

Based on the Ethereum platform, the PoS consensus protocol used in a previous study [103] was built using miners' sacrifices of part of their stack to eliminate the price gap caused by power losses. This increases social welfare and provides the optimum price for both buyers and sellers. Power loss compensation is achieved by applying punishment for unsuccessful mining, where the value of rewards will be less than that of the miners invested in stake.

The prosumer bidding and selling prices scheme described in a recent report [104] incentivizes prosumer behaviors to achieve regional energy balance and low carbon emissions. The trading framework forms a distributed network to exchange both energy and carbon allowances using BC under standardized and self-enforcing SCs. Carbon allowance trading was considered part of the revenue, and selling more allowances resulted in increased revenue. Hence, the cost of carbon allowance should be included in energy generation costs to improve the use of RES. BC provides an auction price platform decided by individuals.

Hamouda *et al.* [59] proposed a BC with two calls. The first call is to create a market transaction with unconfirmed status, and the second is to mine a real-time transaction to confirm it. This process mirrors the physical power flow in the system by BC cash flow. The marketing price was calculated and cleared using an external uniform marketing price model, integrated with sensitivity analysis, using power flow to compute the loss factor at each node. Therefore, incorporating the loss factor will lead to accurate and efficient load dispatch. Hence, setting the market price depends on both generation and demand bidding and the calculated loss factor. Moreover, the price of time concept was applied so that the market could respond to load needs on time. However, any failure to fulfill the power obligations and breach the created SC in the first call will apply a penalty while creating the real-time block in the second call.

Oprea *et al.* [105] applied different indicators to assess the efficiency of the market mechanism using BC. These indicators are necessary to ensure that trading between the parties in the power network will not affect the system's reliability and efficiency. Therefore, the BC platform records offer and consumption bids, optimizes the power blocks, and maximizes social welfare regardless of the auction price mechanism. Moreover, market performance is assessed by two indicators: degree of local sufficiency and weighted average market-clearing price. The first represents both self-consumed and trading quantities and overall market players' consumption, whereas the second is applied during certain time intervals to calculate the weighted average prices of all the traded quantities. BC allowed more room for trading by adjusting the initial bidding and offering prices and, hence, allowing more transactions to improve trading performance. Moreover Samuel *et al.* [106] proposed a demand-based pricing policy by categorizing the EVs in three types: special (fire brigade, ambulance, police or government), local (registered one with a certain haring station area) and outside EV (unregistered vehicle within a certain haring station area). Also, the geographical location and time of demand are considered to maximized the social welfare and utility. These parameters are reshaping the energy prices. Actually, three scenarios were applied on this study. The first one was to give lower energy price during on -peak hours for special EVs to encourage them in energy trading. The second scenario was to organized the charging stations energy trading during on-peak and off-peak hours based on available energy and the defined threshold of charging stations. Some extra charges and tokens are applied in this trading to ensure fairness between the local EVs and outside. The third scenario, considered the cases with energy trading between EVs and charging stations in different areas (urban and rural). The energy trading was applied in both private and public BC to ensure high security and privacy of the EVs' owners. The results of this study were found that observable reduction in the energy price compared to multi-parameter pricing scheme, fixed pricing scheme and time-of-use pricing scheme (ToU). The study gave good hup in how to build a pricing energy scheme which is applicable in BC platform.

The five basic processes and requirements for enabling transactive energy operations are [107]:

1) Participant registration and qualification
2) Negotiation

3) Operation (market-clearing, dictating the bidding and contract obligation rules)
4) Measurement and verification (market settling, verification, and validation of actual transactive energy system exchanges)
5) Settlement/reconciliation (establishing arbitration and reconciliation)

BC should be used as a foundation for the basic transactive energy system to ensure data immutability in a distributed database and validate/authenticate SCs through a consensus protocol throughout peer life cycle management.

Based on the above, a well-designed pricing infrastructure for BC energy applications requires full coverage of different aspects and knowledge to improve market operation, social welfare, system objectives, and system efficacy. The following points should be considered when designing pricing structures for BC to create sophisticated pricing systems.

A. BIDING/AUCTION PROCESS

The energy exchange between participants (consumers, prosumers, and utilities) in the modern power network (e.g., SG, smart city) is typically performed through a SC. SCs in BC platforms should be enhanced to dynamically calculate the pre-unit energy exchange price based on the energies generated from RESs and utilities in the overall grid. All system parties must define their requirements when registering in the BC, and these can be amended or updated later within the agreement thresholds. After demand and supply are defined, the bidding process can be initiated for the transaction of SCs through the BC platform to leverage its features of privacy, anonymity, security, and confidentiality [108].

Furthermore, market-oriented auctioning and bidding mechanisms can be set as methods in the BC trading platform. The auction method is suitable for short-turn trading, whereas negotiation (bilateral) is applicable for future transactions [105]. Many pricing infrastructure auction methods using BC are proposed, such as generalized second price, uniform price (double auction), Vickrey-Clark-Groves, Pay as Bid [105], and open English Auction [109]. BC can be used as an administrator, designed for trading mechanisms under an approved auctioning role. To ensure high competition, the selling price set by the prosumer should be less than the utility rate. The BC consensus protocol supports this competition by adjusting the joining price, particularly in the local electricity market.

B. DATA COLLECTION

In modern power networks, SG uses the IoT to collect data from physical equipment and devices to optimize the decision-making process and improve the performance of services to users. The consumption data were measured using sensors and smart meters at different resolutions. Therefore, advanced metering infrastructure is needed to monitor and analyze energy usage by consumers and energy production by prosumers. In this case, BC requires the utilization of the IoT and smart meters in the SG to prepare for simplified integration purposes [91]. Smart meter data must include necessary energy information from customers, prosumers, and utilities. These data will be frequently sent to the BC network to calculate the demand and supply curves. The smart meter can also be used to send the offer prices, status of the power flow, EV charging modes and behavior, and other power network parameters to improve financial and operational issues.

The development of the BC price structure should include the security checking process of the smart meter data because these data are highly dependent on BC consensus decision-makers. In terms of data ownership copyright issues, the BC structure must be built using a secure protocol, including verification and validation development criteria.

C. POWER NETWORK CONSTRAINS

In distributed systems with available RESs, the power system and local electricity market structures will impact the potential ancillary services that can provide RES. Nevertheless, integrating RESs into DSs introduces new operational and planning technical challenges [110]. Consequently, participants in SCs must evaluate transactions by calculating the power flow through any suitable software before it is sent to the BC process [111]. The pricing infrastructure developer of an energy application must consider the power constraints as the main factor to accept the transaction and add marginal revenue for those who provide ancillary services to the power network. It is necessary to achieve a combination of optimal power flow and energy trading to create a balance between network operation and the final criteria.

D. ENVIRONMENTAL ASPECTS

Electricity markets are forced by environmental regulations towards new clean energy sources, thus increasing interest in renewable-based DGs. DGs with RES provide an optimum solution for energy consumption, particularly for areas with high electricity demand. RESs have lower carbon emissions than fossil fuels, which greatly improves the efficiency of the electricity supply. Generally, carbon emissions caused by prosumers and utilities must be tracked and formulated in the form of monetary compensation. Considering this, BC can assign carbon allowances to prosumers based on their carbon intensities and reduction targets. Carbon allowances should form part of P2P transactions and part of the marginal revenue of the BC pricing infrastructure. Moreover, carbon allowance trading must be considered one of the most important trading terms in BC framework trading. Carbon emissions data can be obtained from a smart meter by linking it with the amount of energy produced or consumed.

It is vital to redesign the pricing scheme of P2P energy transactions in a decentralized trading framework so that prosumers can reshape their behavior to achieve a carbon emission reduction target. However, a separate design for carbon emissions and energy markets will not comply with decentralization purposes; therefore, the cost of carbon emission must be added to the energy cost [104].

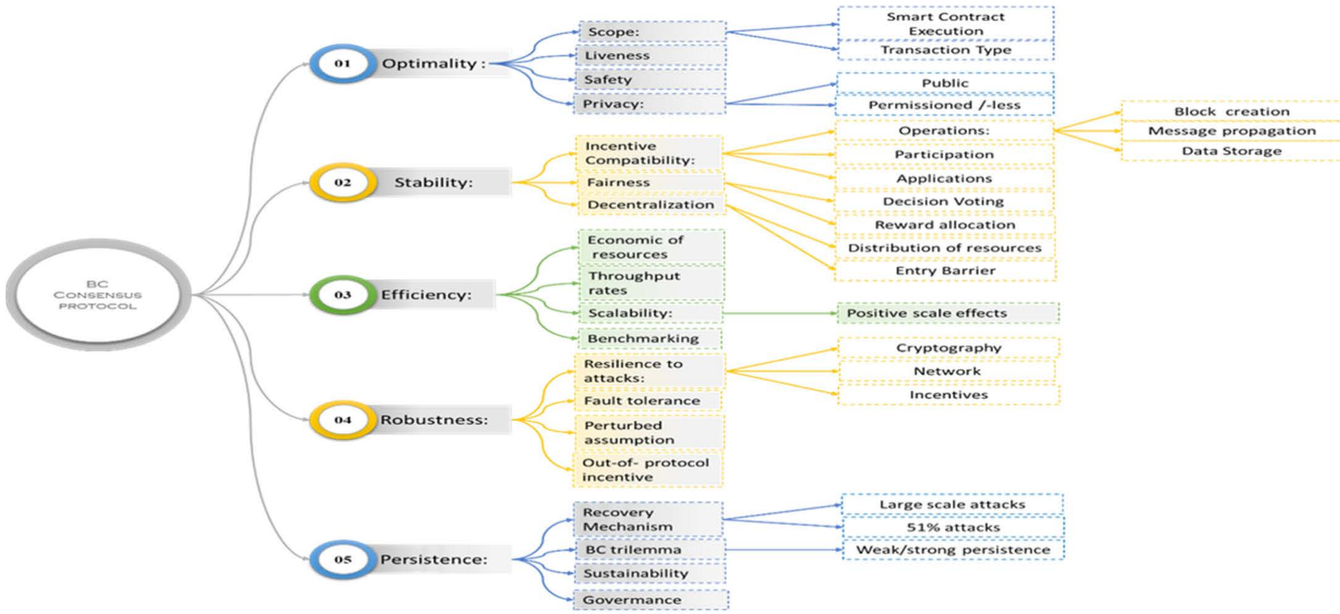

FIGURE 7. PRESto systematic frameworks for BC consensus protocols.

E. CONSENSUS PROTOCOL SELECTION

As mentioned in Section II, the selection of the consensus protocol is vital for fulfilling the role of the BC platform in energy applications. Leonardos *et al.* [37] identified the different dimensions for comparing consensus protocols in detail. **Figure 7** illustrates the systematic frameworks for BC consensus protocols, known as PREsto.

- Optimality: maximizing the quality of BC outcomes
- Stability: incentives for proper behaviors to reach the desired outcomes
- Efficiency: protocol utilization behavior in time, self-energy consumption, and network bandwidth
- Robustness: protocol performance during any perturbations
- Persistence: recovery ability for any force to operate far from the equilibrium conditions

The BC price infrastructure should consider the number of transactions that can be handled during P2P trading. If the consensus procedure is delayed to validate the transaction, the price structure will not be valid or practical. The mining power consumption should also be considered because node owners will be paying for it directly. Therefore, the BC platform needs to ensure the satisfaction of each participant when looking for profits and benefits.

F. INTEGRATING AI IN BC

AI technology powers new digitalization models by mimicking the human mind in problem-solving and decision-making by leveraging computer programming and machines. AI is a promising technology with possible applications in all sectors, including health, energy, communication, marketing, IoT, and manufacturing. Moreover, AI will drive the solution for the future SG including decentralization, digitalization and data analysis for the energy system [112].

With respect to energy applications, modern power networks have developed new concepts in SG technologies, such as demand-side management, P2P energy trading, load scheduling, DGs, RESs, and prosumers. The characteristics of RES power generation bring additional challenges in terms of power stability and flexibility, which affect the reliable operation of the power network. AI technology has shown the capability to improve the energy management system in SGs [113]. AI techniques can be classified into four approaches: monitoring, analysis, decision making, and autonomic energy management architecture.

Ahmed *et al.* [114] highlighted four major roles of AI in the energy sector:

- Simulation and improvement: suited for optimization and forecasting (prediction) applications in modeling, planning, and simulation work.
- Investment and market: cover market players investment models
- Sustainability and safety: optimizing and predicting the maintenance schedule and providing protection measures for the energy structure.
- Services oriented for the customer: facilitating customer share in energy systems, demand management, billing, and smart homes.

AI requires a large amount of data to control complex energy networks, improve decision-making, and increase system reliability. Additionally, the need for large amounts and different types of data at different levels of SGs is important to allow AI to complete autonomous tasks, such as self-healing, self-configuration, self-optimization, and self-protection [113]. Moreover, AI facilitates the efficient use of

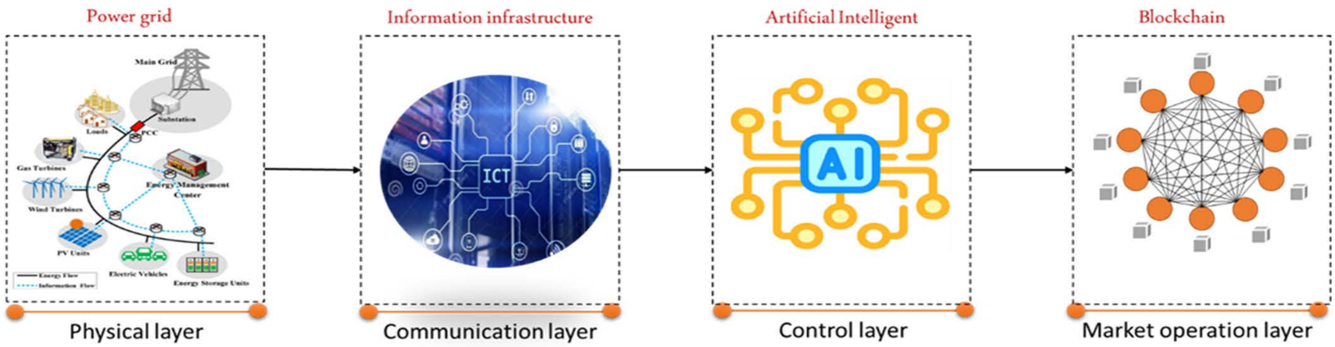

FIGURE 8. Incorporation plan between BC and AI in power grid.

RES by optimizing and maintaining an economic load dispatch. Nevertheless, adopting AI in the energy sector may be challenging due to the requirement of high-quality data and security, technical structure issues, lack of practical expertise, outdated power system structure, and increased cyberattacks [114]. The challenges of using AI are vast and would require to be reviewed in a separate paper and should be researched further in the future.

BC and AI are innovative technologies in the energy sector. BC creates a decentralized platform for trading energy, whereas AI provides intelligent autonomous optimization and can act as a decision-maker for power system operation [115]. The concept of integrating AI into a BC by incorporating them with power grid or SG is shown in **Figure 8**. Integrating the benefits of AI, such as automation, computation efficiency, scalability, and adaptability, into power systems will increase the engagement of the prosumers into the decentralized energy market and encourage them to achieve zero emission target. However, lack of dynamic and decentralized price policy measures can be a barrier for facilitating the engagement of prosumers which will be explained more in the challenges section. **Figure 9** summarizes the basic concept of price in infrastructure based on the data flow between parties in a power network. It can be noticed from the graph that the BC process is built to collect the require data from smart device (e.g., smart meter), validating the transaction and gives feedback to the participants. In this concept, the ISO's data send to BC platform is vital to approve the transaction because it has to ensure reliability and security of the power network while energy is exchanged between the presumes themselves or between prosumers and utility. The BC platform shall apply any pricing strategy to built the cost of the energy based on the biding offers which are received form the participants.

V. CHALLENGES AND CONCERNS OF BC IN ENERGY APPLICATION

Nodes are considered the backbone of BC technology, and different consensus techniques are used to form the required validating process. Despite the specificity of consensus technologies in terms of methodology, mathematical computation process, energy consumption, and performance, some of them fail to succeed in their mission. Bellini *et al.* [8] highlighted several forms of consensus failure, including a lack of consensus, domination, cheating, and poor performance. A lack of consensus occurs when nodes cannot reach an agreement; therefore, BC will be considered ineffective. Domination occurs when attackers create pseudonymous nodes or identities to mislead the network and manipulate its goals. Cheating is an attack targeting the participants in a network that willingly maintains a parallel chain such that attackers present a parallel reality that does not exist in the BC. Regrading poor performance, the transaction process is affected by the consensus algorithms, latency, chain complexity, and network instability, which results in more time to converge towards any single chain. This highlights the importance of addressing privacy and security issues in BC because it touches on the main feature of this technology and its ability to succeed in possible applications.

A. PRIVACY AND SECURITY ISSUES

Concerns regarding privacy and security are the most significant challenges for BC applications, including in the energy sector. Any technology that threatens privacy in the energy sector will not be accepted smoothly and will delay adoption. Because of the transparency feature of BC, users remain pseudonymous and linked to a public address. Therefore, exchanged information is exposed to network participants. By default, using stored data in BC chains may reveal users' personal information, allowing the possibility of easy tracking and data leakage. This contrasts with anonymous users who are untraceable and unidentifiable [95], [116].

It is important to determine the weaknesses or vulnerabilities of any proposed BC platform, particularly in the initial stages [41]. Some details and public keys are visible in the BC network, which leads to a high probability of information leakage if privacy and security requirements are not considered.

Security vulnerabilities often appear in emerging technologies, such as BC. They open a path to cybercrime on their users [92]. Hash-based, or 51%, attack is a well-known BC security issue [41], [117]. This type of attack occurs when

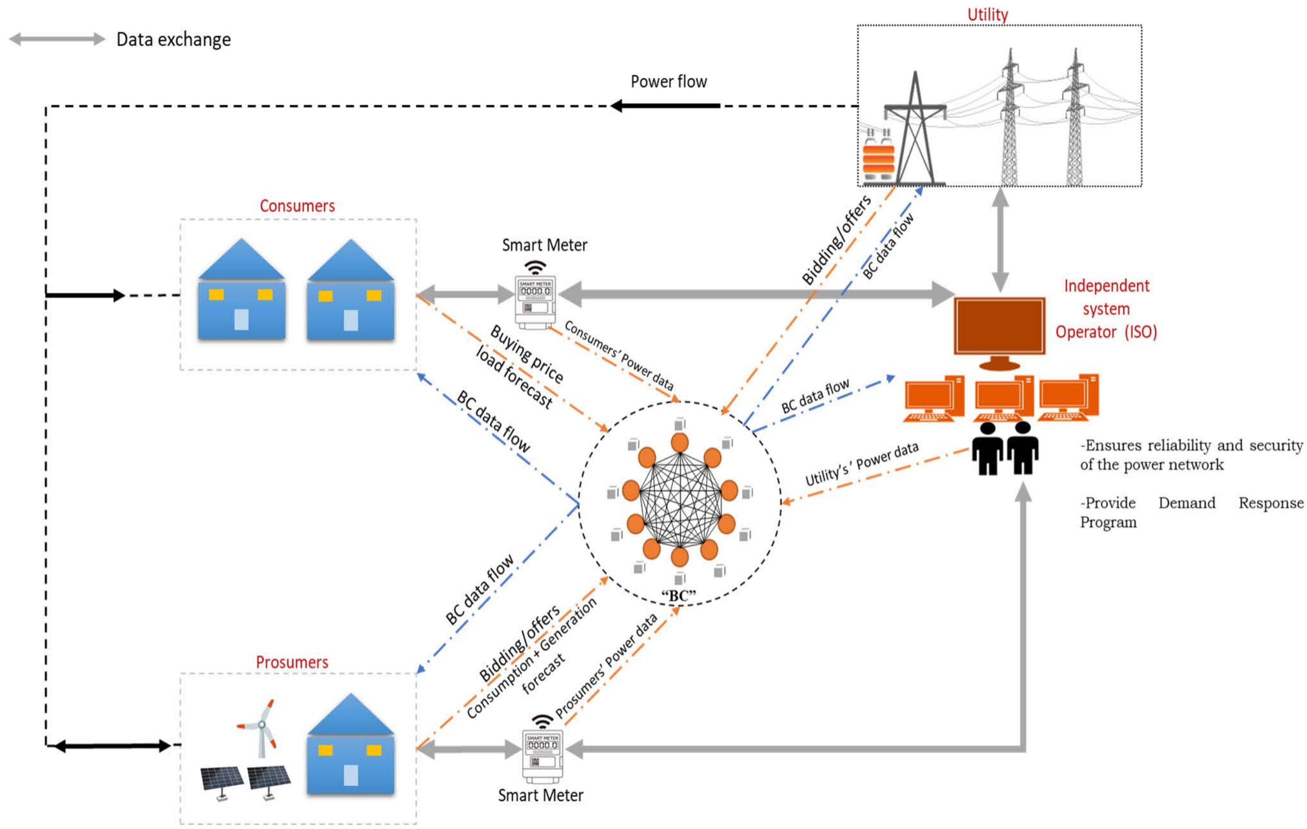

FIGURE 9. Basic concept of BC price infrastructure and data flow.

BC miners' control 51% of the hash mining (or computation), causing a curb in the new storing block process, double spending, inhibiting the remaining miners from confirming the block [88] explained that invaders could exploit this vulnerability in different ways, such as overturning operations, eliminating and adjusting transaction ordering, and obstructing normal operations of mining and operations confirmation. Another attack with block-withholding threats is a selfish mining attack [118], [119]. In this attack, attackers work secretly in mining blocks to increase rewards and obtain revenue more than the ratio of mining power. Another type is Sybill attacks, which hamper consensus protocols for ensuring security [8].

New techniques must be applied to improve anonymity and complicate finding the connections between users and transactions. Some techniques can be considered good practices, such as deanonymization (transactions, change addresses, behavior-based clustering), which links different addresses to the same user. Other techniques presented in [95] also enhanced and improved anonymity, such as zero-knowledge proof, homomorphic commitments, composite signature, ring signature, mixing service, and blind signature.

B. DRAWBACKS

Despite the interjectional attribution of BC technology and its great ability to achieve the goals of the distributed system, there are still some drawbacks and limitations that should be considered, such as [97], [88]:

- For transaction accomplishment, nodes need more rewards and increasing costs
- Transactions need more time to be validated even without third-party intervention.
- Probability of risk of error if the human factor is engaged
- Wasteful as every process must be repeated to validate each transaction.

In BC, a lack of identity privacy/preservation, mutual authentication, and system integrity are additional issues that make BC vulnerable [80]. In addition, a high number of nodes reduces BC performance. BC has better scalability than centralized systems; however, dynamicity is required to provide additional nodes that update the transaction regularly. In general, the lack of scalability is due to the underlying consensus mechanism [120]. For example, PoW consensus has low efficiency and high resource consumption, increasing the expense of operating and maintaining large systems. In contrast, BFT requires a huge number of information transmissions between parties, which can increase the work load for sending, receiving, and processing transactions.

Other drawbacks include data propagation and latency during the BC process. Data propagation refers to the movement of the same data from one node to another. Latency is an indication of any delay occurring in the data while traveling from its original point to another point (node); the higher the delay, the higher the latency. High latency is caused by data propagation (long distance in the communication network) or by routers and switches which are responsible for transmitting data. Therefore, further tests are necessary to check the scalability, data movement timing, and power consumption for all proposed solutions [72].

C. GENERAL CONCERNS IN BC PRICING INFRASTRUCTURE

The cost of deploying and operating BC technology is unknown and difficult to predict [95]. Testing the potential cost requires many experiments, especially for large physical systems, such as the energy sector. New costly infrastructure is needed to develop a BC system that includes custom information, communication technologies, and software [96]. The cost is related to expensive cutting-edge technology to ensure data integrity and improved security in the distributed ledgers of the BC system (e.g., integrated smart meters with the grid infrastructure). Designing a local market structure is a vital issue for the new role of prosumers in matching profits and benefits between them and the system. More studies are needed to standardize trading platforms in terms of their role, pricing, regulation, and transactions. However, the operation perspective issue focuses on how easily AI models can be integrated into physical operations and the constraints of the power system. This requires a move towards digitalized and interoperable power systems with intensive digital and physical interactions between both physical and digital layers [121].

Furthermore, regulations, standards, and organizations are required to make BC applicable to real-world applications. More effort is needed to build new technical standards for the proper use of BC energy, including standards for electrical bill identification, privacy, security, energy efficiency, cost efficiency, and ancillary service management of the grid. Finally, the user's awareness of how to use and deal with BC plays an important role in accepting the technology. Encouraging end-users to implement this technology requires a logical initialization prior to the implementation phase, including raising the level of knowledge of BC technology.

VI. CONCLUSION

This review paper aimed to provide a comprehensive overview of energy applications using BC technology. This review found that BC is a promising technology that provides feasible solutions to many problems facing energy applications such as EVs, MGs, RES, storage systems, and RES ancillary services. The ability of BC to combine reduction in trading costs with improved efficiency in security and privacy could encourage participation in energy trading. Despite the technical challenges facing BC, BC can facilitate the management of DGs in MGs and are useful for energy trading and optimization applications. However, integrating BC requires expensive technological infrastructure upgrades to deal with huge amounts of data and perform fast, high-security trading. BC provides a great mechanism for prosumers to access a satisfactory energy price while maintaining and promoting system sustainability. Moreover, it encourages using clean energy, thus reducing carbon emissions. Nevertheless, the energy cost in BC should be linked to carbon emission allowances, so the behavior of the consumer, prosumer, and utility can support zero-emission targets.

Furthermore, this paper diverged from past reviews on this topic by focusing on price infrastructure requirements and related considerations. The BC pricing framework concept comprises transaction data, aggregated bids, and offers. In addition, the type of data, environmental aspects, and power constraints reshape the pricing behavior of energy trading; therefore, adynamic processes are suitable for BC processes. However, these processes require highly accurate decision-makers. Therefore, combining BC with AI is necessary to overcome user integration issues in terms of trading, control, and regulation functions.

Finally, this paper discussed the challenges and concerns facing the application of BC in the energy sector. Privacy and security issues are still plaguing BC technology in most applications, creating a barrier to BC adoption. Moreover, the pricing structure in BC lacks an appropriate local market design, and more intensive research is required to overcome this problem and standardize the structure.

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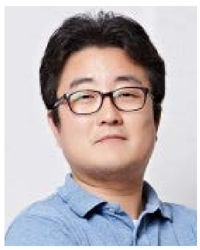
TARIQ AL-ABRI received the B.Sc. degree in power systems and energy engineering from Sultan Qaboos University, in 2010, where he is currently pursuing the M.S. degree. His research interests include the energy application with Blockchain integration.

AHMET ONEN received the B.Sc. degree in electrical-electronics engineering from Gaziantep University, in 2005, the M.S. degree in electrical-computer engineering from Clemson University, in 2010, and the Ph.D. degree from the Electrical and Computer Engineering Department, Virginia Tech, in 2014. He is currently working as an Associate Professor with Sultan Qaboos University. His research interests include the smart grid and sustainable energy technologies.

RASHID AL-ABRI (Member, IEEE) received the B.Sc. degree in electrical engineering from Sultan Qaboos University, Oman, in 2002, the M.Sc. degree in electrical engineering from the Curtin University of Technology, WA, Australia, in 2004, and the Ph.D. degree from the Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, ON, Canada, in 2012. He is currently the Director of the Sustainable Energy Research Center (SERC) and an Assistant Professor with the ECE Department, Sultan Qaboos University. His research interests include power electronics applications, renewable energy, power quality, energy efficiency, power systems, and smart grid applications, as well as power systems stability.

ABDULNASIR HOSSEN (Senior Member, IEEE) received the Ph.D. degree from Ruhr University Bochum, Germany, in 1994, and the postdoctoral degree from the University of Kiel, Germany, in 1997, both in the area of digital signal processing. Since 1999, he has been with the Department of Electrical and Computer Engineering, Sultan Qaboos University (SQU), Oman. In June 2013, he became a Full Professor, where he has been the Director of the Communication and Information Research Center, since June 2017. His research interests include signal processing in general with emphasis on biomedical signal processing, telemedicine, classification of signals, artificial intelligence, machine learning algorithms, and neural networks. He obtained the DAAD Research Scholarship Awards, in 2000, 2003, 2006, 2009, 2012, and 2018.

AMER AL-HINAI (Senior Member, IEEE) received the M.Sc. and Ph.D. degrees from West Virginia University, USA, in 2000 and 2005, respectively. He was a Visiting Professor with the Masdar Institute (MI) of Science and Technology, United Arab Emirates, from 2012 to 2016. He was the Founding Director of the Sustainable Energy Research Center (SERC), Sultan Qaboos University (SQU), Oman, from 2017 to 2021. He is an Associate Professor with the Department of Electrical and Computer Engineering and the Deputy Vice-Chancellor for Postgraduate Studies and Research (DVC-PSR) with SQU. He is the Chairperson of the IEEE Oman Section, from 2014 to 2018; and holding a Consultant grade as classified by the Oman Society of Engineers. He served as a member and the Chairman for the Authority for Electricity Regulation, Oman, from 2011 to 2017. He served as a Presidium Member for the Energy Regulators Regional Association (ERRA), from 2016 to 2017.



JAESUNG JUNG (Member, IEEE) received the B.S. degree in electrical engineering from Chungnam National University, South Korea, the M.S. degree in electrical engineering from North Carolina State University, Raleigh, NC, USA; and the Ph.D. degree in electrical engineering from Virginia Tech, Blacksburg, VA, USA. He is currently a Faculty Member with the Department of Energy Systems Research, Ajou University, South Korea. His research interests include the development and deployment of renewable and sustainable energy technologies.

TAHA SELIM USTUN (Member, IEEE) received the Ph.D. degree in electrical engineering from Victoria University, Melbourne, VIC, Australia. He is currently a Researcher with the Fukushima Renewable Energy Institute (FREA), National Institute of Advanced Industrial Science and Technology (AIST), where he leads the Smart Grid Cybersecurity Laboratory. Prior to that, he was a Faculty Member with the School of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA, USA. He has been invited to run specialist courses in Africa, India, and China. He has delivered talks for the Qatar Foundation, the World Energy Council, the Waterloo Global Science Initiative, and the European Union Energy Initiative (EUEI). His research has attracted funding from prestigious programs in Japan, Australia, EU, and North America. His current research interests include power systems protection, communication in power networks, distributed generation, microgrids, electric vehicle integration, and cybersecurity in smart grids. He is a member of the IEC Renewable Energy Management WG8 and IEC TC 57 WG17. He also serves on the Editorial Board of IEEE Access, IEEE Transactions on Industrial Informatics, *Energies*, *Electronics*, *Electricity*, *World Electric Vehicle Journal*, and *Information* journal.