Chapter 6

c0030 # Blockchain and its application fields in both power economy and demand side management

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s0010 ## 1 Introduction

p0015 In our modern world, technology, innovation, and digitalization all surround us and affect society from top to bottom. Remarkable opportunities and spectacular technological developments have great impact on the power industry in essence, recently. Therefore it is widely accepted that there is an urgent need to transform the traditional power system ushered in by Nicola Tesla some 120 years ago to the smart grid in new scientific horizon [1].

p0020 The traditional electrical grid has major limitations in terms of operation, management, and construction. In fact, this architecture was designed for fulfilling the needs set up in the last century [2]. It takes time to respond to dynamic changes in demand and/or generation due to applied vertical, multilevel [3], and centralized control mechanisms. Primarily radial construction and cybersecurity vulnerabilities cause to decrease reliability and resiliency parameters, which mean long-duration interruptions will occur in end-user services. Passive loads, in particular, are not controllable, and the system operator can only develop strategies in supply side to provide power balance at all times. In this structure the restricted energy storage system (ESS) potential has been evaluated as a significantly important issue in power system operation especially in case of any excess or shortfall in power [1]. Therefore it is not wrong to indicate that the capability of self-healing and self-restoration has been limited in the traditional grid without incorporating smart grid applications.

p0025 On the other hand, electrical energy is transferred from generally large-scale central energy plants established far away from the end users by enabling only one-way power and information flow [4]. Fossil-based resources (natural gas,

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coal, petroleum, etc.) have been utilized excessively in power system operation from its establishment up to now, which cause to increase greenhouse gas (GHG) emissions. In the light of recent events in climate, it is becoming extremely difficult to ignore GHG emission-based impacts on our ecosystem. Acid rains, ozone layer depletion, and increased carbon footprint are some of the most notable consequences that should be considered globally from government and legislative authorities' perspective.

p0030 To achieve key targets in terms of decarbonization of the power industry and combatting climate change, there are significant endeavors for deploying renewable energy sources (RESs) in the supply side. It is important to highlight that penetrating highest proportion of RES into the power grid could not be evaluated as an option; it has become an obligation [5] for providing a sustainable model. Besides environmental regulatory requirements, volatile energy prices of fossil-based resources and energy security issues also make energy transition necessary from nonrenewable sources to RESs [6]. Especially in case of any energy crisis, conventional systems would not be sufficient to meet increasing electricity demand.

p0035 Therefore, in the last few decades, photovoltaic (PV), wind, hydropower, biomass, and other renewable resource-based generation systems have attracted significant attention of the energy sector decision-makers and utility companies considering the aforementioned negative outcomes. The increasing investments have paved the way for growing this sector tremendously and accelerating technological innovations on this application fields thanks to the considerable amount of contributions. For example, according to United Nations' Sustainable Development Goal No. 7, it is aimed to increase the proportion of RESs in the global energy mix considerably in the year 2030 with the aim of supplying affordable and clean energy for all of us [7]. European Union has also made important attempts for expanding RES capacity by 27% in 2030, which is one of the most popular commitments that is accepted by all European countries [8]. It is important to indicate that the global average temperature can be kept between desired ranges if and only if renewable generation is increased by 23% for today to more than 50% in 2050 [5] with remarkable incentives. In fact the radical cost reductions in procured energy prices of PV and wind have important impacts on facilitating their integration into the power system and being the primary choice from the end-user side [9]. Thus 100% RES concept has gained importance in our modern world related to the aforementioned revolutions, and it has strongly been supported by governments and stakeholders.

p0040 The rapid transformations in the generation system have paved the way for increasing investments on a smaller scale, decentralized, and spatially dispersed systems instead of conventional large-scale centralized plants [10]. The main aim of this transition is to operate the sophisticated architecture efficiently with maximizing the reduction of both transmission and distribution power losses, reducing energy costs, and obtaining coordinated structure for future sustainable and resilient societies [11]. Therefore it would not be wrong to mark that high integration of utility-scale and domestic-scale RESs has a profound impact on the worldwide energy market that lies in the transactive energy concept, which gives incentives to all parties for trading energy based on the decentralized architecture [12]. These unprecedented changes in energy infrastructure and services have triggered to improve new strategies of grid operation, management, and new models in the context of commercial targets considering the reliability needs.

p0045 Unlike the all aforementioned advantageous issues, there are some important challenges to be taken into account, which are the intermittent, weather-dependent characteristics of RESs that seriously affect their power output patterns [13]. Therefore the vast majority of studies have been carried out to investigate the impacts of their dilute and disperse behavior on the power grid with a growing body of literature from the system operators' perspective. It is to be emphasized that such nondispatchable resources may cause supply-demand imbalances, voltage regulation problems, frequency instabilities, and other power quality disturbances in the electrical grid, due to their stochastic nature that should be handled [14]. Overall, these operational challenges that can affect the interconnected power system performance adversely highlight the need for incorporating different flexibility sources to maintain safety, robustness, and security. One of the top priority solutions is pointing out that the spinning reserve should be taken into consideration and become a necessary part of the operational tools. ESSs such as battery energy storage, flywheels, compressed air storage, pumped hydro, and superconducting magnetic sources [15] are one of the most fast-responding types of spinning reserve. Moreover, they can provide fast backup with responding load fluctuations in real-time and effective management strategies in case of any disturbances to smooth the overall voltage and power profile for maintaining normal network operation. On the other perspective the presence of ESS enables to reduce grid dependence and paves the way for performing decentralized mode in an optimal fashion with the objective of decreasing GHG emissions, energy, and operating costs and increasing power reliability [16].

p0050 Alternatively, electric vehicles (EVs), as one of the most promising storage technologies, are likely to become a key component for real-time applications with the ability to perform vehicle-to-grid and grid-to-vehicle modes [17]. It is obviously seen that the transportation system has also been transformed from fossil fuel-powered vehicles to emission-free, eco-friendly EVs due to the same concerns mentioned for generation side. From the power system planners' perspective, the highly penetrated EVs could play an important role in network operation based on the idea of backup storage or ancillary service provider to ensure supply-demand balance and meet the end-user requirements. These kinds of potential power sources will become increasingly popular in the future especially with the implementation of demand-side management strategies in the smart grid paradigm provided that technical, social, infrastructure, and policy challenges have been solved [15].

p0055 Apart from the mentioned ESS technologies, the concept of demand side management (DSM) has drawn significant attention and presents a promising solution for system operators to maintain voltage/frequency stability, defer generation plant construction, and increase energy efficiency [18]. Normally, energy generation increases in response to an increase in end-users' demand in traditional power system operation. However, ever-increasing demands and the widespread adoption of distributed generation enforced to change the mentality and demand side become new axiom area with the help of outstanding developments in the fields of smart grid technology. And DR is one of the most popular techniques of DSM that enables end users to reduce/shift their electricity consumption in response to electricity prices or operator's requests [19]. The communication and information technologies and an advanced metering infrastructure (AMI) enable two-way communication between the utility company and the end users for implementing load shifting/load reduction strategies by taking into account operational benefits in the controllable platform of smart decentralized structure [20].

p0060 Therefore all of these can be evaluated as a forerunner of modern power grid architecture, which is currently undergoing drastic changes in both supply and demand sides. In the smart grid era, it is expected that almost every end user can produce their own energy by installed on-site distributed generation units called as prosumer. With incorporating smart meter technologies, two-way communication will be available and provide information exchange between distribution system operator (DSO) and end users that presents significant advantages in terms of controllability, observability, security, and stability [21]. The end users can observe their production and consumption at the same time while it is possible to participate in DR programs depending on the real-time electricity prices broadcasted by DSO. All the aforementioned changes paved the way for unleashing a revolution in power system that requires operating in decentralized, peer-to-peer fashion instead of centralized methods.

p0065 Processing, storing, and supervising the huge amount of data have become one of the most challenging issues considering hundreds of millions of terminals of the utility grid. Also, there is a growing concern about cybersecurity vulnerabilities in case of any single-point failure due to the existence of only one control center in a centralized operation manner [22]. Furthermore, sophisticated and complex communication infrastructure required costly investments that do not have to meet our modern world necessities [23]. To address these issues, blockchain or distributed ledger technologies (DLT) were mainly presented to facilitate peer-to-peer decentralized transactions between nodes without requiring any third-party participation [24]. A better management and operation could be ensured by blockchain-based implementations and applications, reducing the system's dependency on the utility in a decentralized architecture.

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## s0015 2 Blockchain technology in different areas including power economy

p0070 This emerging modern world was driven by an unending stream of next-generation communication and information technologies, which are Internet of Things (IoT), cloud computing, and big data [25]. Similarly, blockchain is one of the greatest innovations among emerging technologies that would ultimately propel us into our modern age. In fact, it is the underlying technology of Bitcoin that was the major milestone in establishing a decentralized architecture. Bitcoin, the world's first cryptocurrency, was presented in 2008 by an unknown author or group of authors calling themselves as Satoshi Nakamoto [26]. The implementation of Bitcoin in 2009 triggered a huge amount of innovative scientific inquiry. Seemingly, this marks a crucial turning point facilitating peer-to-peer and distributed transactions in many fields of power economy.

p0075 Recently, utility decision-makers, startups, financial institutions, national governments, and the academic community have shown an increased interest in blockchain applications [24], and it has been comprehensively investigated from different points of view. Obviously, it is against today's traditional sophisticated financial payment architecture. In this system, any single point of failure causes undesirable consequences due to the vulnerability of both technical failures and malicious attacks. Also, to operate the system, transacting parties should trust central intermediary that introduces extra costs, time-consuming exchanges, inefficient concurrency control, and insecure data storage [21].

p0080 However, on the other hand, blockchain is a digital and distributed data structure that enables to make a transaction between two mutually unknown and otherwise unrelated parties directly without the existence of any trusted central authority [27] that sounds very new, creative, and innovative. Generally speaking, the system is operated by the created technical codes and rules that are determined by the community, that is, by the network users in the system independent of any legal financial authority or any regulatory body [28]. This is one of the oddest yet most brilliant core characteristics of blockchain technology. What remains unclear is how such an operation is possible considering the long-lasting effectiveness of the third parties.

p0085 In fact the banks are eliminated, and each individual network members (nodes or clients) become a new bank that is capable of storing the information of any digital transactions, records, and executables in their distributed ledgers as compared in Figs. 1 and 2. Each event is ordered chronologically and copied to every node in larger forms sequentially by attaching to previous blocks in chain form [24]. It is possible for network users to reach the blockchain and view its contents and participate in the consensus process as an active member [29]. A primary concern of this architecture for operating the system without the assistance of any third party is double spending and fraud. As we all know the cryptocurrency is digital that can be generated after executing particular

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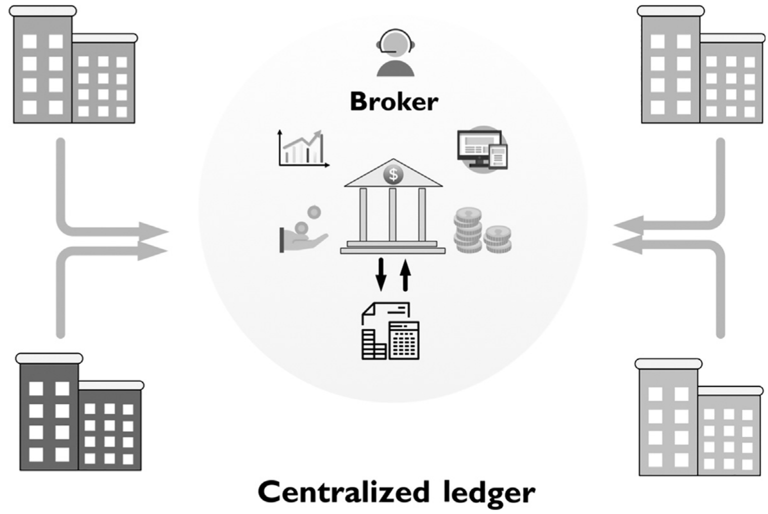
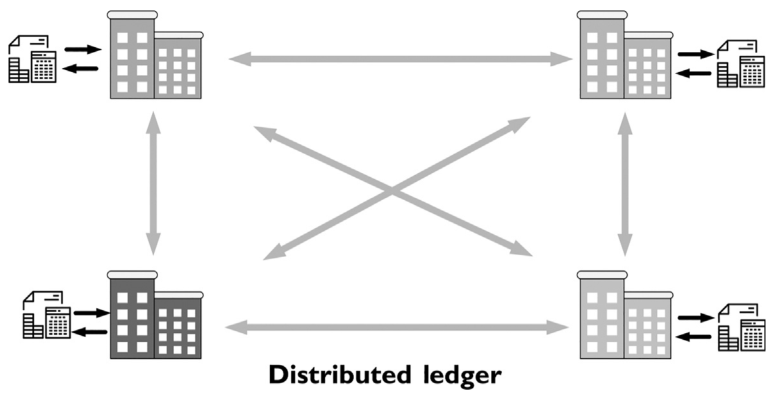



f0010 **FIG. 1** The architecture of traditional centralized ledger system.




f0015 **FIG. 2** The architecture of distributed ledger system.

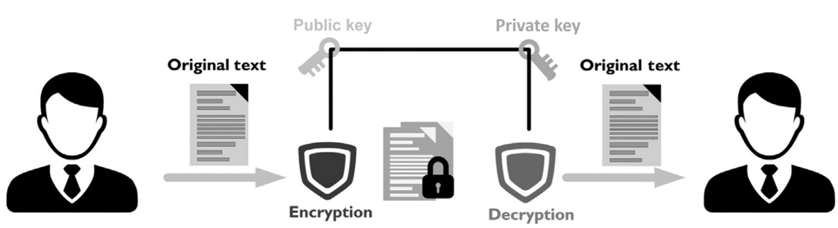
cryptographic algorithms and protocols. So, it is important to prevent copying the same amount of currency on the individual network users' computer, mobile phone, or workstation wherever it is stored and sending them to the receiver point more than once.

p0090 To address the questions that have been raised about the security of the blockchain-based system operation, there is a simple yet clever concept that enables to keep users' identity anonymously with public-key cryptography [30], an asymmetric cryptography protocol, is used in this architecture. Two different cryptographic keys are provided for each user, namely, private key and public key comprising of numeric or alphanumeric characters [31].

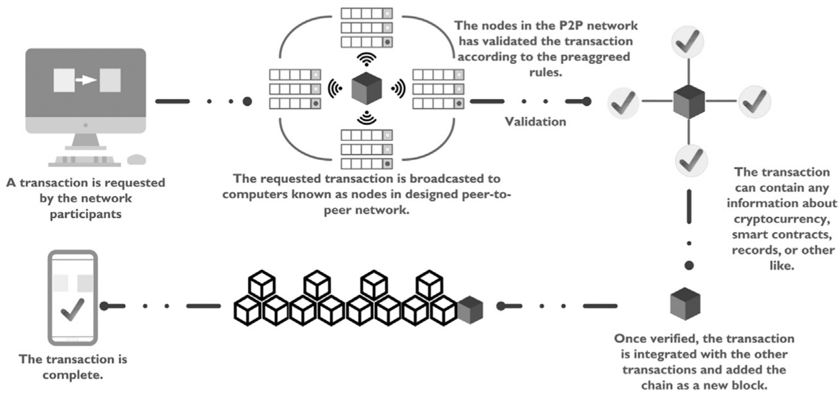
The private key is randomly generated, and it is to be kept secret for users' own security that is used in signing their own transactions [32]. However, they could not be considered independent of each other, that is, there is a mathematical relationship between them enabling to generate from private key to the public key, while the reverse process is almost impossible thanks to the robust encryption codebase [31]. Therefore it can be indicated that there is no problem for sharing the public key with other participants, yet it makes the user addressable in the network. Users have been known by their digital signature combining private and public keys that makes the transaction extremely secure for all of the participants. The cryptography procedure is illustrated in Fig. 3. Basically, in this process, the payment message consisting of the recipient's public key, address, and amount of payment has been created by the sender and transferred to the receiver end accompanied with sender's digital signature securely. This cryptography provides an important opportunity by updating every transaction in the network participant's distributed ledgers and the organized time-stamped blocks even their offline copies are held in the blockchain, which shows its permanent and traceable architecture. So, this makes changing data or information irrevocably hard thanks to advanced cryptographic techniques [25].

p0095 On the other perspective, it is expected from network users to validate whether the transaction is performed appropriately or not for the purpose of building trust between participants without any central authority. However, there is an urgent need to prevent appending the data in blockchain whoever wants to do it. Otherwise the system will unable to withstand malicious attacks and encounter some important challenges to be handled. This mentioned issue has received considerable critical attention, and cryptographic tokens are presented as a solution for encouraging the honest nodes to add only executed transaction information on the system [29]. Widely known as miners can be identified as a major contributing participant in the network ensuring that false data cannot be inserted and time-stamped blocks cannot be tampered by any untrusted members making blockchain trustable, secure, and resilient.

p0100 When any user attempts to transfer a certain amount of digital currency from her/his electronic wallet to another user's, the transaction is to be verified by the network miners and formed them as "block" to integrate the chain. The basic process is illustrated in Fig. 4. A major problem with the confirmation process




f0020 **FIG. 3** The illustration of cryptographic process.

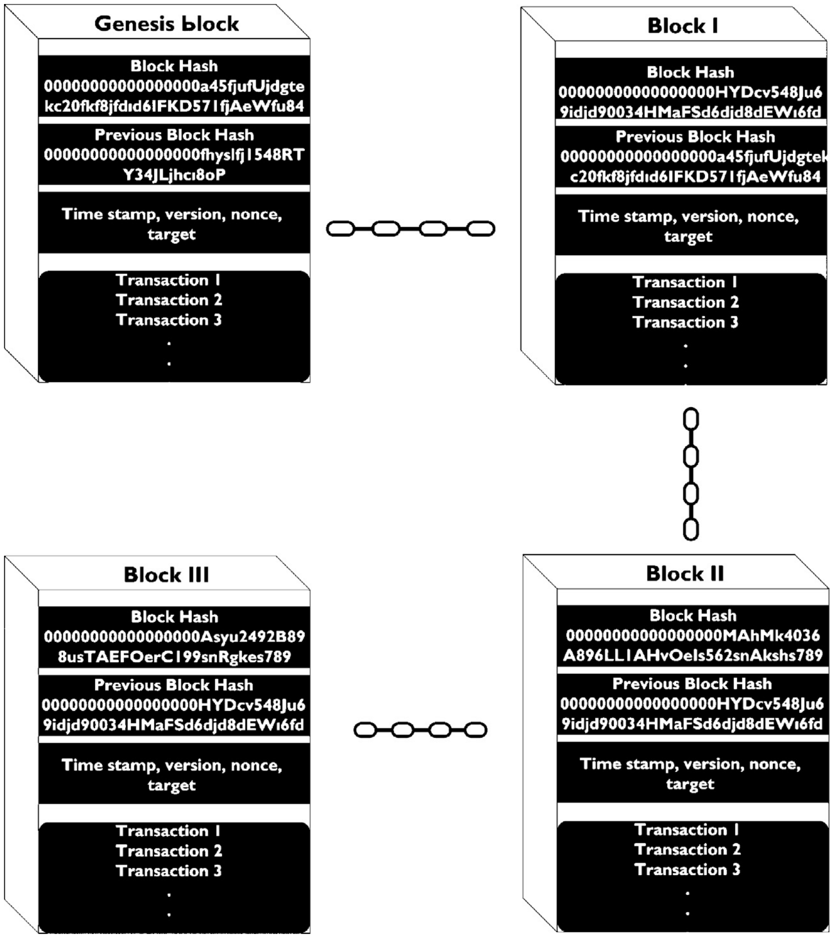



f0025 **FIG. 4** The basic process of validated blockchain.

is finding the hash output of block, which is related to the stored information. It is worthy to note that using a specific cryptographic hash algorithm enhances the security of data drastically similar to the private and public keys. The illustrative example of hashing of blocks is depicted in Fig. 5.

p0105 The hash function converts the input in string form (numbers, letters, media files, and/or symbols) of any length into the fixed length of hash output (aka signature) that can vary (32-bit or 64-bit or 128-bit or 256-bit) based on the utilized hash function. For example, Bitcoin uses SHA-256 in its process for producing unique hash outputs [33]. To extend the knowledge, it is necessary to draw our attention to the distinctive characteristics of hashing cryptography that should be considered. Entering the same hash input results in creating the same hash output, that is, changing the input multiple times has any impact on output characters. Also, it is sensitive to any changes in input value; even only one letter or number means that entirely different hash output will be produced after a process. Moreover, one of the most impressive qualities of hashing is that one-way transformation is possible in this architecture, which is not possible to obtain the original data set from hash output [34]. Herein, miners have great endeavors to solve a cryptographic problem (finding a hash output) that will help to be rewarded with cryptographic tokens in return for appending the verified block into the chain. This complex mathematical problem, in particular, requires high CPU resources and a considerable amount of computational work from the miners' perspective that the process should continuously be repeated to reach the signature (hash output) requirements [35]. These all specifications of blockchain architecture make major and indeed an essential contribution to the field of achieving securely and reliable distributed transaction by implementing advanced cryptographic techniques.

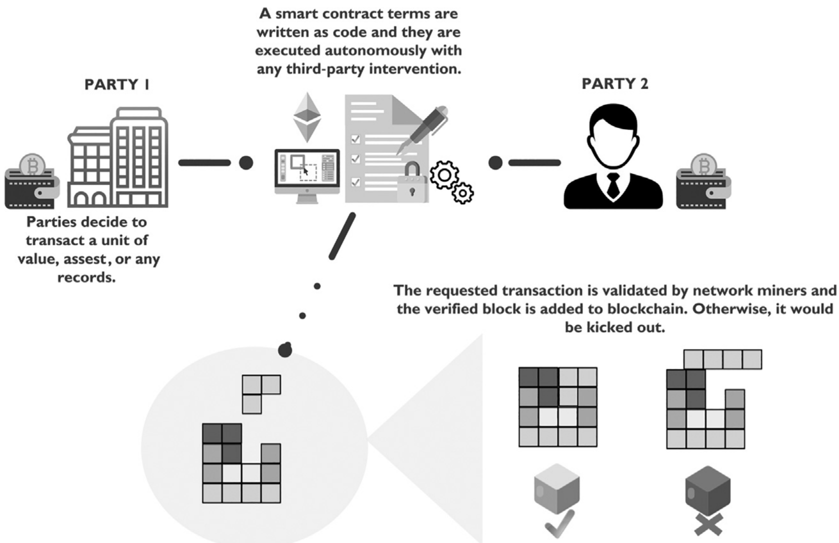
p0110 The study made by UK Government Office for Science [36] makes a major contribution to research on combined blockchain technologies with smart




f0030 **FIG. 5** The illustration of simple Bitcoin blockchain architecture.

contracts and provides an exciting opportunity to expand our knowledge of utilizing its potential as much as possible. The illustrative example is shown in Fig. 6.

p0115 There is great number of important areas where it is possible to improve novel business solutions by integrating smart contracts. The terms were first described in the 1990s by Nick Szabo, a notable computer scientist and cryptographer and who defined it as [37]: "a set of promises, specified in digital form, including protocols within which the parties perform on these promises." Although a smart contract presents a considerable amount of advantages and opportunities, it was not a convenient time to implement its real industry [38]. The emerging technologies, Bitcoin, and blockchain revitalized the smart




f0035 **FIG. 6** The illustration of smart contract-based system operation.

contract paradigm and paved the way for developing new strategies in different application fields. Especially in 2015 the platform of Ethereum was released, which is one of the most useful things ever discovered for smart contracts and immediately leading participants to build their own distributed applications as "autonomous entities" [39].

p0120 Technically speaking a smart contract is a self-enforcing agreement between parties, mutually unknown and otherwise anonymous counterparts, which is capable of executing the rules automatically in satisfying certain conditions [40]. Needless to say, this interesting concept presents the decentralized architecture, removes the intermediaries (lawyer and/or other central agency), and determines its own rules with cryptographic code, which is completely different from a traditional contract framework. Within the blockchain context, the agreed terms are embedded in computer code written in solidity as one of the most brand-new programming languages [41] and are established as sophisticated if-then statements. In other words, this contract has been prepared to contain all regulations, details, and enforced programmed rules to run based on If-This-Then-That (IFTTT) logic in which the directives are executed sequentially [39].

p0125 A vending machine can be evaluated as a primitive example of smart contract in which the transaction is executed based on the encoding rules into a machine [42]. Anyone inserts the required amount of coin for purchasing what she/he wants to and presses the numbers related to that product. After, it is to be controlled by the machine similar to the smart contract whether the correct amount of fund is inserted or not. If the answer is yes, the product will be ejected

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together with the change (if extra money is inserted in the beginning of the process). Here's also a typical example of a smart contract for expanding our knowledge on this concept [43]: "let's say you and I have agreed that if I write you a history of bitcoin, you'll send me $10 on my birthday this year. We can do that via a legally enforceable contract, which involves lawyers, notaries, and so on — or we can do it via Ethereum. In the latter case, you put $10 worth of smart coins in escrow, and when the terms of the contract are met, those coins are released to me. If I don't meet the terms of our agreement, the coins are released back to you." So the instructions are executed automatically based on the script written beforehand if and only if predefined conditions are satisfied [39].

p0130 Overall the developmental stages of blockchain technology can be divided into three consecutive groups considering the intended audience. Virtual cryptocurrencies (e.g., Bitcoin) have emerged in Blockchain 1.0 that was the crucial turning point in terms of indicating to start the new digital era [44]. Blockchain 2.0 is seemingly accepted as the major milestone of enabling transaction beyond cryptocurrencies by executing smart contracts autonomously [32]. These two of them are the forerunner of the next-generation blockchain 3.0 in which it is possible to implement the distributed architecture in many fields, such as government, health, science, and IoT. The history of blockchain-related innovative technologies is illustrated in Fig. 7.

p0135 Therefore it would not be wrong to mark that blockchain is one of the greatest technological innovations that has paved the way for opening a range of new opportunities for both financial and nonfinancial areas. There is a great potential to change especially financial system entirely thanks to the peer-to-peer distributed structure; the critical issues can be handled by this foundational technology with transforming the paradigm from third trusted authority to trusted math [45].

p0140 Today, it is well known that from transportation systems to supply chain managements and energy trading implementations to communication, health services are operated by centralized points of control, which is not possible to think of real-time implementations without it. However, the presented innovative features enable blockchain to find many application fields in our modern world that have the potential to revolutionize society completely without a doubt. Marc Andreessen, the doyen of Silicon Valley's capitalists, has also indicated last year that the blockchain-distributed consensus model is the most important invention after the Internet itself. On the other perspective, Johann Palychata from BNP Paribas has pointed out that Bitcoin's blockchain and the software is such an inventions that will have great impacts on finance and beyond like the steam or combustion engine [46]. Thus the radical changes are expected in a vast range of fields from stakeholders by overcoming the challenges in an innovative way. It is important to combine emerging brand-new technologies (such as machine learning) with blockchain to improve the efficiency and current practices of systems and to accelerate the speed of services [47]. A growing body of literature studies and important pilot projects has been conducted with great contributions to extend our knowledge of this technology

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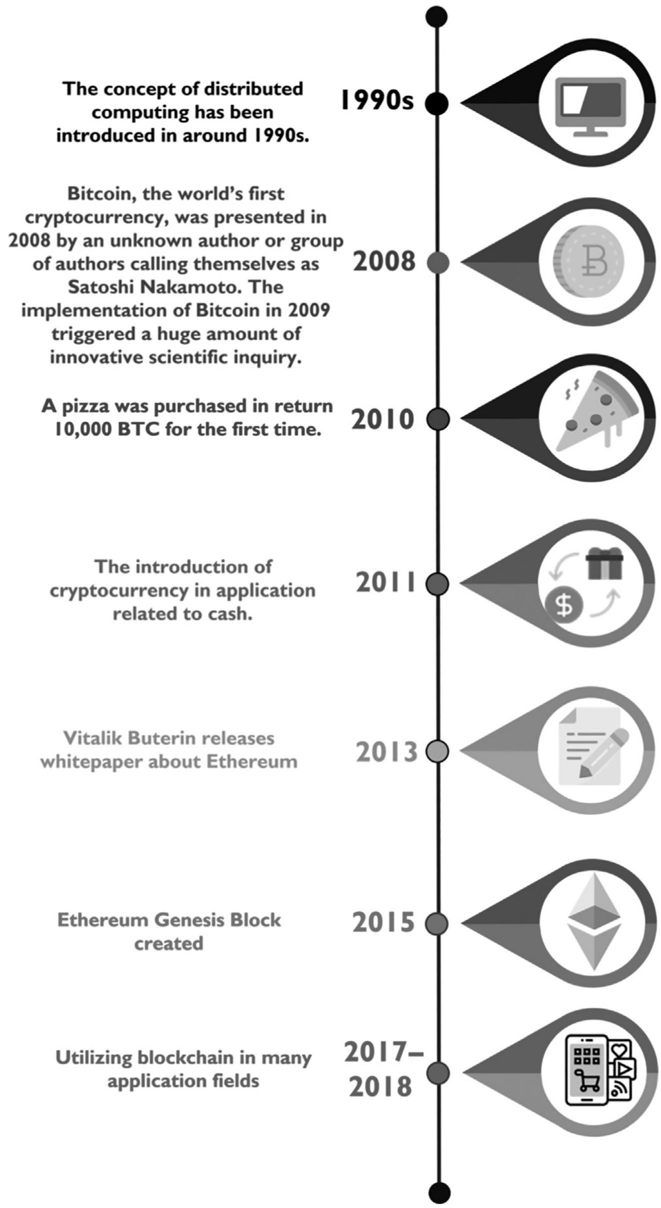
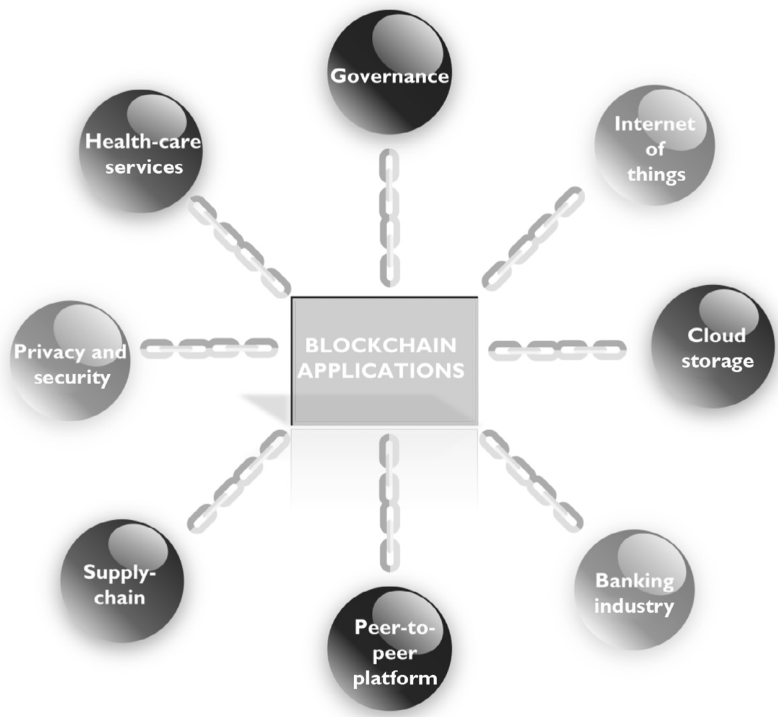



f0040 **FIG. 7** The history of blockchain-related technological innovations.

both in the field of theory and practice. Some of the most widely implemented areas are summarized in Fig. 8 and explained with examples in blockchain-based system architecture providing trusted interaction between participants and technology.




f0045 **FIG. 8** Blockchain application fields.

p0145 As expected, the real adoption of blockchain technology will find a primary area in the financial industry that creates drastic changes in the system operation and enforces to replace major parts of their model. It is widely known that banking system is a huge network of integration of different organizations, which allow the transaction of digital assets, funds, or values among multiple parties (lenders, clients, capitalists, investors, etc.) [48]. The main drawback of the conventional banking system is that the processes are completely controlled by central authority, which makes protecting the customer's privacy and securing the exchange data difficult [49]. This system is not robust to withstand any cyberattacks, that is, the great number of stored data can be tampered, and as a result, it is not difficult to leak customer's personal information that makes the operation safety poor [50]. Moreover the payment clearing process is sophisticated, lengthy, and costly, consisting of a range of complicated procedures that cause delayed settlement with low efficiency [51]. All of the mentioned technical issues should be certainly considered, and the system should be upgraded or transformed; otherwise, these may cause notable consequences.

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p0150 To address the existing challenges, the concept of blockchain is one of the most important candidates that has a potential to reshape the entire economy, considering its advantages for achieving secure exchanges between parties by **blocking** the intermediate financial institutions. The asymmetric encryption, point-to-point payment, consensus mechanisms, and the other features mentioned will make the system more secure, cost-effective, and extremely efficient [52].

p0155 Questions have been raised about how financial institutions may react to the implementations of blockchain technology into their conventional system. Surprisingly, they are not evaluated in this incorporation as a threat for the models; yet, business enterprises have attempted to modernize traditional banking system, utilizing the innovative approaches as much as possible [46]. They are seeking new avenues in this field, supporting their thoughts through the research and experimental studies for providing widespread application. For example, Rain Lohmus of Estonia's LHV bank indicated that blockchain technology is suitable for some financial implementations due to being the mostly tested and secure architecture [46]. It is also possible to point out that there are great endeavors of world's biggest banks in terms of looking for a novel and alternative system operation with blockchain and establishing a platform in financial market. The banking giants are JPMorgan, State Street, UBS, Royal Bank of Scotland, Credit Suisse, BBVA, and Commonwealth Bank of Australia, and they have an opportunity to collaborate in blockchain sector for the first time since 2015 by making considerable amount of significant contributions [53].

p0160 According to the relevant surveys including 200 global banks, it was expected that nearly 15% of banks would implement blockchain by 2017 which is extensive rate. Moreover, 66% of the banks will start to use commercial blockchain in following 4 years which is dramatic rate, has been marked by IBM, one of the most prominent companies [54].

p0165 To enhance transparency, reliability, and risk reduction, about 40 Japanese banks agreed in principle and established a consortium entitled Ripple to utilize blockchain technology in real-time transactions in a cost-effective way. The fraud events, double-spending problem, are the main issues that are avoided as possible during exchanges funds, values, or digital assets [55].

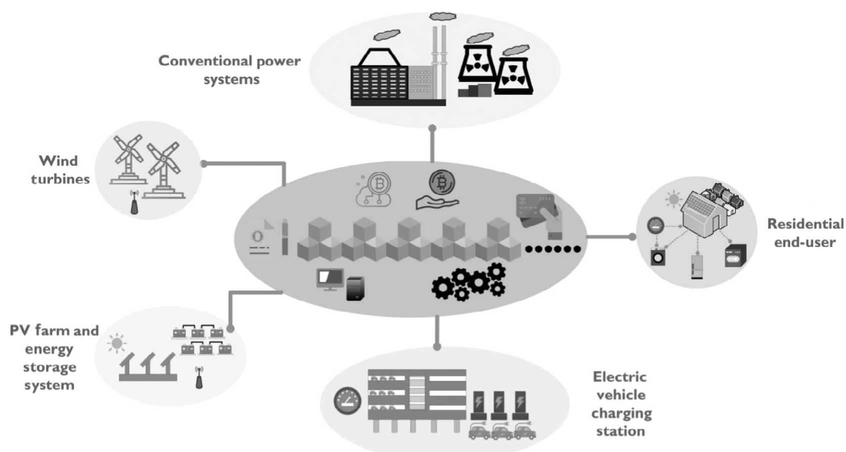
p0170 From the other perspective, blockchain-based system design should be also considered in smart grid environment for again security and data protection concerns. The state-of-the-art combination of communication and information technologies into the traditional grid makes the system "smarter" [56]. It aimed to transfer electricity in an economic and efficient fashion to commercial, social, and industrial areas and decrease the power losses in the lines. One of the most tremendous benefits of smart grid is that the system operators are always aware of the conditions of utility grid thanks to the bidirectional information flow; the smart homes, smart building, and smart campus in general smart communities have established smart devices based on AMI key technology that sends meter readings, billing, and consumption profiles to the operator.

However, there is an urgent need to eliminate cyberattack vulnerabilities of the smart grid that is suitable environment for this threat. All of the activities conducted on the Internet are evaluated as open sources of these types of attacks.

p0175 On the other hand, one of the most dramatic changes happened on the demand side, where the new actors have been integrated into the market operation, called as prosumers who are consumers also with on-site production facilities generally RESs [57]. The smart grid concept let all of the participants have communication on the online environment and pave the way for peer-to-peer energy trading between parties in a decentralized way. However, the concerns about protecting personal information are the main drawbacks for convincing the end users in terms of participating in the energy trading process.

p0180 It is highly important to ensure data transparency, data provenance, and trustworthiness between participants during peer-to-peer energy trading process, which also requires a transaction of a great amount of data in real time. Therefore blockchain technology has been found as an appropriate candidate to address the challenges. It has been indicated that this concept will help to enhance system efficiency considering current practices and procedures and also the improvement of IoT platforms can be accelerated by combining both of them in decentralized manner based on The German Energy Agency report [58].

p0185 There are considerable amount of literature studies aiming to resolve the major problems of combined blockchain and smart grid concepts. The illustration of integrating smart grid applications into blockchain is shown in Fig. 9. Tampering the meter readings is prevented by the presented studies in [59,60], which provides storage and secured the data processing. Also the studies presented by [61–62] are focused on the other main technical challenge of the system operation as high cost functions. For the purpose of increasing




f0050 **FIG. 9** The illustration of blockchain and smart grid application areas.

renewable-based energy trading in smart grid, "NRGcoin," a digital currency, was represented in [63]. The Australian company "Power Ledger" has attempted to conduct an experimental study in which peer-to-peer energy trading is executed by blockchain-based technology, which is an important example on this field [64].

p0190 Apart from mentioned implementations, blockchain technology has also gained massive importance from the academic community and utility decision-makers to operate and coordinate the system efficiently that is highly secure and cost-effective. A recently conducted survey has taken our attention to EV community and enforced the related parties to determine new business models with incorporating emergence technologies as also indicated in Table 1. Shortly the high amount of payment transactions, nearly $140 billion, has been performed for

t0010 **TABLE 1 The practical initiatives for providing blockchain-based platform for EV charging [68–72].**

| Actor | Business | Implemented country | Generic description |
|---|---|---|---|
| MotionWerk | Start-up | Germany | Sharing the charging stations with the other EV users via mobile application, thanks to the developed Share&Charge platform |
| eMotorWerks | Private company | United States | Enabling peer-to-peer EV charging to the market collaborating with Share&Charge platform |
| Charg Coin | Tech start-up | United States | Facilitating finding the charging stations for EVs and providing secure marketplace in terms of transacting energy |
| Lab10 Collective | Cooperative | Austria | Fully automated charging and payment system for EVs based on blockchain technology |
| Easelink | Private company | Austria | Industrialize Matrix Charging with blockchain payments |
| Slock.it | Private company | Germany | Collaborating with MotionWerk to improve Share&Charge platform |
| Enexis | Utility | Netherlands | Attempting to develop IOTA-enabled transaction for performing EV charging |

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binding the settlements in this industry that should be taken into account [65]. A great deal of documents, data, and approvals are to be coordinated while collaboration and reallocation are ensured among vehicles with applying blockchain. Since this technology presents significant opportunities especially in security issues, the significant studies primarily aim to establish a trust-based platform and improve the level of trustworthiness [66,67].

p0195 It is evidently seen that the blockchain technology has wide range of implementation areas both financial and nonfinancial. Apart from aforementioned applications, gaming industry, notary services, cloud-based distributed storage systems, health-care services, and even in music industry are potential environments utilizing its advantages and make their system more robust, transparent, secure and resilient [46, 73].

## s0020 3 Blockchain with DR applications

p0200 The electricity consumption might vary according to end-user behaviors, seasonal effects, and even a weekday/weekend difference. Independent system operators make severe efforts to respond to this variable load demand [74]. To the date of the emerging smart grid paradigm, this steadily increasing demand has tried to be tackled by considering the supply side in the traditional power system. Moreover the power system is considerably changed by including the new generation units such as PV and wind in supply side and the new players such as EVs and ESSs in demand side. Due to the new load types and the high penetration of renewable-based generation units, the imbalance between supply and demand sides must be handled to provide a more sustainable power system [75]. Therefore the operational flexibility that allows the DSO to take new axioms on both of the supply and demand sides has gained more importance in recent years, and DSM comes into prominence as a promising solution. According to the Electric Power Research Institute (EPRI), DSM can be defined as [76] "DSM is the planning, implementation and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e. time pattern and magnitude of a utility's load. Utility programs falling under the umbrella of DSM include load management, new uses, strategic conservation, electrification, customer generation, and adjustments in market share."

p0205 By implementing DSM the power demand of consumers can be reduced in peak hours or shifted to the nonpeak hours as depicted in Fig. 10. To include the end users into the power system operation environment, DR strategies are accepted as the widely applied method of the DSM because of its feasibility and quick response [77]. End users are encouraged to participate in the operation of the power system in both types of incentive-based or price-based DR programs as a prosumer.

p0210 It is evidently seen that there is an unprecedented rate of incorporating DR strategies in power system operational tools to mitigate supply-demand

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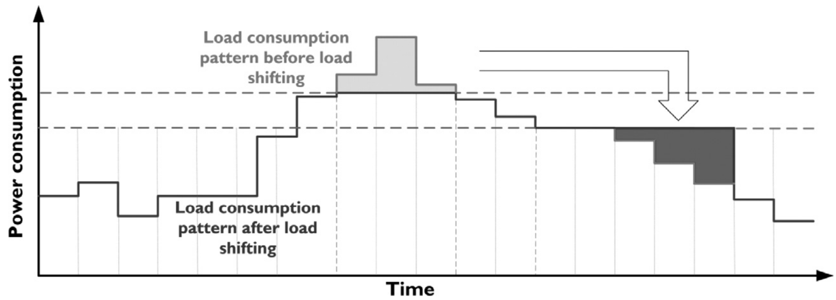


f0055 **FIG. 10** The implementation of load shifting strategy by using related ancillary services.

imbalances due to unpredictable nature of RESs and power consumption patterns of end users. A considerable amount of real implementations were carried out all over the world with significant endeavors of utility decision-makers as indicated in Table 2. For more information about different DR applications, Ref. [74] can also be undertaken.

p0215 As a consequence the future electricity grid, namely, the smart grids, precisely will contain many new actors, especially in demand side to perform a more flexible operation by DR programs [78, 79]. As the number of participants increases, the system security, reliability, and efficiency together with the protection of personal data will not easily be maintained in the current version of the power system operation. At this point the significance of a blockchain-based power system will be sensed. The contract between the DSO and the DR participants can be arranged by using the blockchain so as to provide a more secure, sustainable, and reliable operation.

p0220 Numerous notable companies, stakeholders, giants of foundations, and institutions have genuinely attempted to conduct significant amount of projects and led to joint international consortiums for integrating blockchain-based DR applications into the power system. Similar to the other industries, significant changes and upheavals have been performed in both supply and demand side of the utility grid within the smart grid and blockchain concepts. The investments in RESs, DR implementations, EVs, ESSs, transactive energy models, and other application domains have been increased in recent years, coming from energy transition needs from traditional to the modernized grid architecture.

p0225 To harness the large number and variety of flexibility sources demand reduction capability in a more organized and coordinated way, TenneT (a transmission system operator in Germany), Vandebron, Sonnen, and IBM have joint a consortium that started in 2017. The pilot projects were implemented in the real world and tested in the Netherlands and Germany for the purpose of increasing system performance and achieving system in balance by utilizing the flexibility of electric cars and home batteries. Peer-to-peer trading platforms, open-source for blockchain provider, and batteries are provided by stakeholders jointly involved in the project [64].

t0015 **TABLE 2** DR implementations in practical scale.

| | | |
|---|---|---|
| Focused on controlling a specific loads | Air conditioners | Pacific Gas & Electric Company [PG&E (California)], Commercial & Residential—"*SmartAC program*" |
| | | CPS Energy (Texas), Commercial & Residential, "*Smart Thermostat Program*" |
| | | Austin Energy Company (Texas), "Rush Hour Rewards Program" |
| | | Energex Company (Australia), "PeakSmart AC program" |
| | Pool pumps | Endeavour Energy (Australia), Residential, "PoolSaver Program" |
| | | Energex Company (Australia), Residential, "Pool Rewards Program" |
| | Water heaters | Energex Company (Australia), Residential, "Hot Water Rewards Program" |
| | Irrigation pumps | Southern California Edison (SCE) Company, "Agricultural and Pumping Interruptible Program" |
| | | Transpower Company (New Zealand) |
| Focused on controlling the total power consumption of end-user premises | Contract-based reduction | PG&E (California)—Industrial, "Optional Binding Mandatory Curtailment Program" |
| | | Diamond Energy Company (Singapore), "Load Interruption Program" |
| | | Ausgrid Company (Australia), Commercial & Industrial, "Dynamic Peak Rebate Trial" |
| | Building energy management system | Kyocera, IBM Japan & Tokyo Community (Japan), Converge & OpenADR Alliance & Fujitsu, pilot implementation |
| | | Southern California Edison (SCE) Company (California), Commercial, "Automated DR Program" |
| | Backup generators | TECO & Progress Energy Company, (Florida), "Backup Generator Program" |
| | | Eskom Company (South Africa), "Standby Generator Program" |

*Continued*

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**TABLE 2 DR implementations in practical scale—cont'd**

| | |
|---|---|
| Focused on enabling end users to the electricity market directly or indirectly | New York Independent System Operator (NYISO), (New York), "Day-Ahead DR Program" |
| | New York Independent System Operator (NYISO)—(New York), "Demand Side Ancillary Services Program" |
| | PG&E (California), Industrial, "Demand Bidding Program" |
| | Southern California Edison (SCE) Company, (California), Commercial, "Demand Bidding Program" |

p0230 The blockchain concept has been evaluated as an attractive solution in modern energy market and an important step comes from the Energy Web Foundation ("EWF"), one of the most widely known foundations in the world that creates Energy Web Chain platform for promoting the EVs, renewable energy credits, DR applications, distributed generation system, and the like in the energy industry [80]. Belgium's TSO, namely, Elia, is also an affiliate of EWF and has been aware of the challenges in emerged sophisticated power system in terms of ensuring production and consumption balance while introducing thousands and eventually millions of assets and variable RES installations. As a solution the concept of demand-side flexibility has been taken into consideration and also the pilot project was carried out for commercial and industrial end users in 2013 by Elia. Recently, there is a significant endeavor to construct a blockchain-based application for implementing DR programs automatically considering the grid requirements in balancing market. The developed architecture is aimed to be performed on Tobalaba, EWF's blockchain test network. Sam Hartnett, a member of the EWF team and an associate at Rocky Mountain Institute, indicated his thoughts as follows: "When a grid operator like Elia introduces a new technology like blockchain and puts a strong foot forward, the whole industry adapts-service providers, aggregators, consumers. They've put a flag in the ground for blockchain's potential to change the market." [81].

p0235 Spectral Smart Energy Control Systems have been presented as such an advanced energy management platform that is capable of controlling wide range of energy assets available in the smart grid from distributed local energy resources, battery systems, and smart home appliances to even aggregated mobile loads. One of the most important targets of the project is establishing a blockchain-based market platform for maximizing RES penetration and flexibility resources effectiveness by empowering individual prosumers and/or emerged local energy communities to being an active participant in energy market. The intermediate parties are eliminated, which bring direct, automated, and robust peer-to-peer trading mechanism with complete transparency in their identity and trading details thanks to the developed Spectral Energy Xchange platform [82].

p0240 The project of eDREAM has been qualified to be supported by European Union's Horizon 2020 research and innovation program with the aim of developing a novel near-real-time closed loop optimal blockchain-based DR ecosystem for aiding distribution system operators (DSOs) to operate system under reliability requirements and to maintain its secure, sustainable conditions. The considerable amount of possible flexibility resources has been utilized in ancillary and balancing services while ensuring optimal system operation by aggregators. The blockchain applications have been investigated in decentralized marketplace-driven management with securing the data handling. For testing the developed architecture, three pilot areas are determined in the United Kingdom, Italy, and Greece corporating the Kiwi, Terni, and CERTH Lab Facilities, respectively. For more detailed information, Ref. [83] can be examined.

p0245 The electricity market architecture has been transfigurated from conventional model to novel decentralized and autonomous energy sector that has quite differences with from each other. To address the need of creating a blockchain-powered flexible peer-to-peer trading platform, a London-based start-up Electron launched its adventure in the year 2015 in cooperation with National Grid UK and Flexitricity. For increasing the deployment smart grid applications into the power system, they also present some products that are capable of registrating the meters, trading DR event actions, and managing the distributed energy resources—making all of them easy to trade between distributed parties in an efficient manner. The consortium targets to take the advantage of blockchain technology as an enabler of flexibility while ensuring security and transparency of the developed decentralized structure [84]. Alastair Martin, a member of Flexitricity, has indicated as follows: "One of the issues faced by the U.K. energy sector today is metering which measures the contribution of demand-response and could be potentially contaminated by unrelated factors. Sub-metering is key and would allow us to determine the correct level of energy delivery at site, but this requires appropriate information flow and validation. Blockchain technology has the potential able to address this issue successfully and enable us to fully optimise demand-response" [68].

p0250 It can be deduced from the aforementioned explanations that DR program implementations have some points needed to be improved such as the energy intermediaries (aggregators or DSOs) that provide communication with end users on an individual basis. However, this might cause the success rate of the DR to decrease; that is, the received demand reduction requests coming from electric utilities cannot be met by end users for achieving theirs power-saving targets. Being aware of the mentioned issues, Japanese companies Fujitsu Limited and Fujitsu Laboratories Ltd. have made an effort to devise a blockchain-based system for enabling enterprise end users to perform peer-to-peer energy exchange among each other. The developed architecture has applied the system based on real-world electricity data supported also be ENERES Co., Ltd., and as a result, DR success rate was nearly improved by 40% compared with existing implementation. It is expected that the considerable improvement will pave the way for increasing the number of participants into the DR programs that help to give fast responses to the changes especially in peak periods [85].

p0255 Ethereum and smart contract-based transActive Grid (TAG) platform was developed by the LO3 Energy, which makes neighboring residents to perform localized peer-to-peer energy trading and control its distributed resources in grid balancing axioms by implementing DR applications on Brooklyn Microgrid (one of the most famous pilot projects developed by collaboration of LO3 energy and Siemens). To monitor and measure the prosumers' energy variations, transmitting this information to the other end-user nodes in created network and acting upon the available information, TAG elements were designed including computer and meter. The excessive available solar energy produced by end users can be directly transacted to theirs neighbors for improving system performance beginning from the local level [86].

p0260 Optimal operation requirements of distribution power system are taken into account thoroughly, and a platform is aimed to be created by the Hive Power to develop optimal management strategies considering the revolutions, changes, and upheavals on system the model. The participants are incentivized to contribute maintaining the electricity system in balance by effective coordination of their production and consumption values. One of the important features of this developed Ethereum blockchain is that flexibility sources of the local energy communities have been managed optimally by satisfying supply-demand needs for the purpose of maximizing entire community's welfare and meeting system technical constraints thanks to the HONEY algorithm. Also, Hive Token is used in energy trading activities, which is standard Ethereum ERC20 token [87].

p0265 The sophisticated architecture of energy sector has different necessities that should be considered from general perspectives such as existence of vast range of data to be processed fast and need a considerable amount of storage capacity and the like. To address these specific challenges, again, Ethereum-based blockchain was designed by the Pylon Network especially for assisting energy suppliers to get better information about power flows and also provide renewable energy cooperatives. Similar to Hive Power platform, the scalable and versatile system also promotes smart meter (Metron) in combination with blockchain and virtual trades, energy flows are tokenized. Surely, it is possible to dispatch the demand for achieving optimal power flows in real time in distributed green energy network [88].

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## s0025 4 Concluding remarks

p0270 It can be evidently seen that 21st century brings along significant revolutions in nearly every industry especially power system, which all are forerunner of modern society from top to bottom. The long-lasting structures have been transfigurated extremely different ones, making it necessary to introduce brand-new technologies for keeping up with rapidly changing time. Highly penetrated RESs, demand-side management programs, EV integration with both vehicle-to-grid and grid-to-vehicle options, peer-to-peer trading platforms, IoT-enabled smart appliances, flexible control and management systems, machine learning algorithms and others have enforced energy sector stakeholders to find advanced solutions for achieving operate the system in desired targets. The current power system and financial and nonfinancial structures have been transformed from centralized to decentralized and distributed network platforms that also enable information flows at significant number of terminals. Therefore, as the trending topology, the usage areas of blockchain are being widened in nowadays because of the changing architectures, making it necessary to combine advanced technological innovations for managing them in a secure, transparent, versatile, scalable, and authenticated fashion. In this context, blockchain has become one of the latest “disruptive innovations,” and it has taken great attention from utility decision-makers, financial institutions, national governments, the academic community, and industrial stakeholders due to its high potential in terms of reconfigurating society entirely.

p0275 From the other perspective, DR programs are being used to decrease the electric power consumption in peak periods or shift the power demands to the nonpeak periods of the day since its invention. The number of participants in such programs will increase in the future due to the increment of the self-energy production or the desire to control their consumptions. Thus the lack of security in that system including many stakeholders during the operation of the power system is inevitable. In this regard, the incorporated both the blockchain and DR programs can be accepted as a promising solution so as to provide a more secure and sustainable power transaction.

p0280 Overall, there have been great attempts to map out the early stages of power system, drawbacks, changing features, incorporated new technological innovations, and the background of shifting distributed structures, comprehensively. Also the fundamental features of blockchain technology were holistically examined including consensus algorithms, asymmetric cryptography techniques, specific hash functions, and peer-to-peer transaction network. The high diffusion within the business, financial, nonfinancial fields was evaluated from different points of view. Moreover the real practical implications, projects, and startups were elaborated in detail for emphasizing whether the blockchain is only a buzzword or has a chance in a community especially combined with DR strategies.

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