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A Review on Blockchain Technology for Distribution of Energy

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ABSTRACT
The alternative energy generation sources have increased drastically from centralized systems to distributed systems which increases the stability of energy distribution management systems and reduces the distribution cost as well. On the other hand, it reduces the probability of major area electricity blackout chances and decreases the energy distribution loss. For proper distribution and management of energy, there are different types of advanced technologies like artificial intelligence, and the Internet of Things (IoT) available, but a blockchain automated system is one of the best choices and is highly recommended. Various aspects of blockchain technology and energy management system have been discussed in this review paper where a total number of 423 journal papers, articles, and online information sources have been reviewed in the initial stage, and finally, 63 published research articles have been selected for review. There are several topics, including technology overview in energy management systems, blockchain application of energy trading, blockchain technology implementation challenges, distributed energy management system with Ethereum, and a conclusion with some recommendations have been discussed. Blockchain and Distributed Ledger Technology (DLT) are highly transparent, authenticate, and secure systems that can be used for distributing the energy between distributor and consumer without an intermediator which increases the overall efficiency of the system. This paper aims to highlight the blockchain and distributed ledger technology and how it works as well as optimize the transaction processing cost among the participants of the consortium network. This paper will make a significant contribution to the new research work and in the field of energy management systems.
Keywords: Blockchain, Distributed Ledger Technology, IoT, Ethereum, Bitcoin.

1 Introduction

The traditional centralized electricity distribution works vertically and is controlled by a large utility management system [1]. The production and transmission of the electricity into the power grid distribution channels are controlled centrally [2]. The power grid distribution channels then distribute the electricity in the different geographical locations through sub-station and finally, the end-users consume the same from the local sub-stations [3]. The centralized electrical system is very challenging due to the complex network management system, which incurs a significant amount of system losses, increases the production and distribution cost, and ultimately consumers need to pay the high electricity cost which ultimately triggers the national economy [4-5]. The vertical structured system also increases the carbon emission countrywide as well as globally [6]. However, the issues and challenges of the traditional energy system can be improved by implementing the distributed energy management system which may encourage the introduction of the perpetual energy system to generate electricity through using new blockchain and distributed ledger technology [7-9].

In the early days, the traditional energy system was fully controlled by public organizations like power generation, distribution, and commercially selling the electricity to the consumer level. But the distributed energy generation concept can be used to generate electricity in different locations across the country and easily can distribute to the end-user consumer level [10]. The interested private electricity producer company needs to submit their offer and get permission from the Government-owned utility body for generating, distributing, and sell the electricity to the

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consumers [11]. So, the private companies can minimize the production and distribution cost which will lead to reducing the selling cost on the consumers' end.

Therefore, to minimize the production, distribution, and selling cost of electricity; a consortium network called a common distribution power grid need to be established between the private electricity producing companies and the Government energy regulatory body where they can share the excess or non-useable electricity with the help of blockchain and distributed ledger technology [12-13]. Blockchain can replace the legacy energy distribution system with an economical electrical distribution system that will be more transparent, traceable, and easy to manage the entire system [14]. In this paper, we will focus on the distributed electrical system, the scope, and challenges of blockchain technology, and the specific application of blockchain for the distribution of energy.

2 Review methodology

Google scholar search engine has been used to access the papers including research gate, different types of index journals, and web of science journals. We also have visited different related websites to gather information for our analysis and different keywords have been used for the same. In the initial stage, a total number of 423 papers have selected to download for study purposes by using different keywords, similar topics, and titles. Among these 423 papers, the authors have selected 115 papers based on the impact factors of the journals, citations, reviews, conferences, and the quality of the websites. Finally, 63 related papers and articles have been selected for the study where most of the papers were published in the last 5 years.

The output of this study has been summarized in different steps. First, is the technical overview of the energy management system. The second is the use of blockchain technology in energy trading platforms. Third, distributed energy management of Ethereum blockchain. Finally, recommendations have been suggested to solve the issues. Figure 1 displays the methodology of this review.

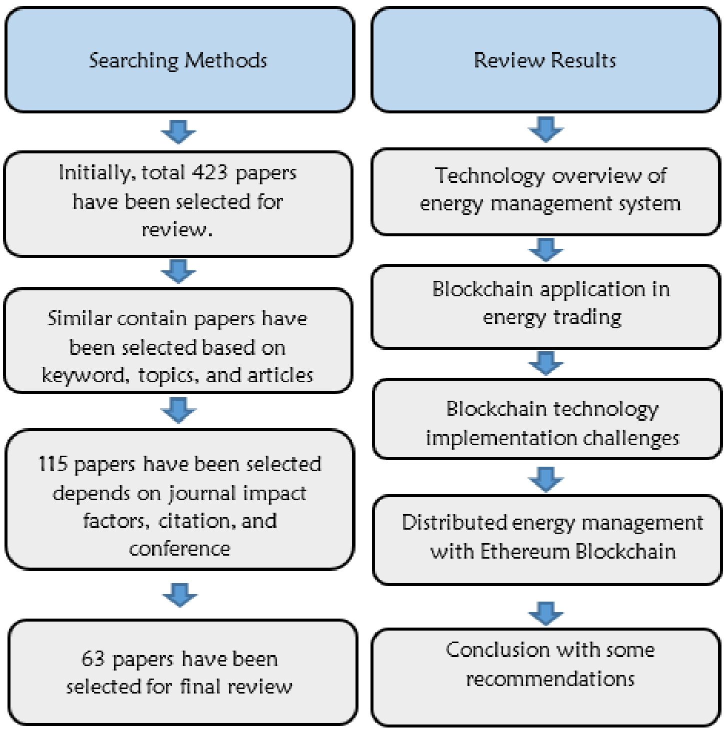

Figure 1: Research Methodology Overview

3 Technology Overview of Energy Management System

This section includes an overview of distributed energy systems, the overview of blockchain and how the technology works, the application of blockchain in the energy sector, and the electricity market.

3.1 Centralized Energy

Centralized electricity production is the large-scale electricity generation system that distributes the electricity vertically. The centralized power station is located far from the end-users and connected to the high voltage distribution lines called the power grid [15]. Most centralized power plants are based on fossil fuel, nuclear, hydraulic, and wind-based power plants. However, an enormous amount of electricity generates from centralized power plants across the globe [16]. Earlier, electricity was generated and distributed independently by each utility company.

Nowadays, a significant amount of electricity is generated and distributed from different geographical locations which are economically cost-effective and ensure high availability. The local utility companies deliver the electricity to the consumers, and it is generated by centralized power plants located at different locations.

3.2 Distributed Energy

Distributed power generation refers to the system which is operated in different locations near the consumers' area. Different technologies are used to generate electricity like solar panels, wind turbines, generators, etc. [17]. The distribution channel may be a single structure or connected to the mini-grid. Normally, it connects to the low voltage delivery lines which help to generate clean power for the end-users and reduce the electricity losses in the distribution channels [18]. Some Common distributed power generation systems in residential areas are:

- Solar based power
- Generator based power (use gasoline or diesel)
- Wind-based power
- Natural gas-based power

Distributed power generation system is introduced to generate alternative electric power from renewable energy sources. The distributed system like solar power, generators, wind turbine, natural gas-based power generation, etc. systems supply the power in the mini-grid that will reduce the emission of fossil fuels and electricity can be provided to the local communities [19]. The distributed power supply system ensures reliable and uninterrupted power supply to the end-users. The shifting from the traditional centralized power system to a decentralized power system eliminates the long-distance transmission lines for transmitting the electricity which improves the uptime and stability of electricity to the consumers [20]. However, sometimes distributed power system becomes more complex due to improper management and human errors. These issues can be addressed by introducing automation which will provide a better management and monitoring system [21].

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Table I: Comparison between centralized and distributed energy systems.

Particulars	Centralized	Distributed
Ownership	Government bodies (independent energy plants)	Household, local, Government, private firm
Finance by	State or Government bodies	Owner, collaboration, consortium, etc.
Availability	The probability of power outage is high due to long distribution lines.	Supply volume is low, but availability is high. Les power outage.
Maintenance	Maintenance is more complicated than the distributed system, due to the large network.	Maintenance is much easier than a centralized system, due to a small distribution network.
Capacity	Large scale production capability and supply the electricity at the national level.	Production capability is low and supplies the electricity for local communities
Connection mode	Connected to the national power grid.	Connected to the off-grid or mini-grid.

3.3 Blockchain and Distributed Ledger Technology

In the year 2009, blockchain technology was introduced by the pseudonymous person or a group through a new cryptocurrency called "Bitcoin" [22]. People are much familiar with the Internet of Things (IoT), still, IoT is dominating for processing the information in different utility sectors [23]. IoT is a fully centralized concept to process data. On the other hand, blockchain is a fully decentralized database network platform. Blockchain is a trusted, immutable, secured platform where the data is represented as a chain of blocks, and transactions are gathered into the blocks [24]. Every block in the blockchain contains data, the hash value of the previous block, time, and other transactional data [25]. Blockchain ensures data security and integrity by using distributed ledger where all the transactional information is available in every node in the network [26]. The blocks are connected cryptographically with the preceding blocks which create the chain of blocks. For example, a simple blockchain structure has been presented in Figure 2.

The purpose of the use of distributed ledger and blockchain technology is the same. It's a digital system where records are connected to the related assets, and at the same time, all the nodes in the network will be updated accordingly with the same information [27]. Cryptocurrency is used for the DLT system, and it verifies the digital transaction into the blockchain network [28]. It is a resilient system that prevents compromising the nodes and keeping the truck records of assets in the network.

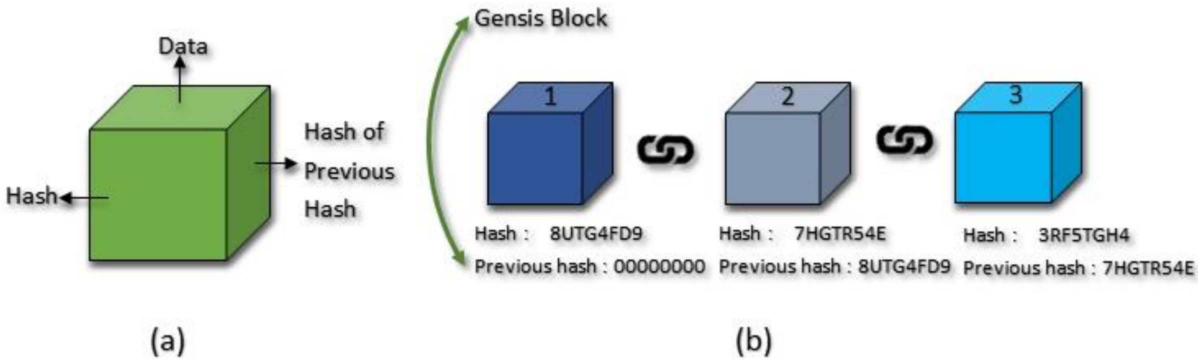

Figure 2: Blockchain Structure

3.4 Types of Blockchain

The blockchain has been categorized into three different types namely public, private, and consortium blockchain. They have different types of characteristics, but the service nature is almost the same. Different types of blockchain are as follows:

3.4.1 Public blockchain

Public blockchain networks incorporate the Proof-of-Work (PoW) consensus protocol. It is an open source-based network where anyone can participate by downloading the relevant code on their computer or any other application-supported device.

3.4.2 Private blockchain

The private blockchain network is controlled by a single authority and this authority maintains the access right of the participants in the network. Only the authorized participants are permitted to do the transaction in the system. In terms of data privacy, it is more secure than other blockchain networks.

3.4.3 Consortium blockchain

The consortium blockchain network is a combination of private and public blockchains. The users' access authority is maintained by the authorized users only. It is faster, scalable, and more transparent compared to the public blockchain.

3.5 Microgrid System

Nowadays, renewable energy is one of the major concerns in the energy industry which needs to be incorporated into the power distribution system [29]. Though there are various forms of the energy distribution system, the microgrid can play a vital role in the same [30]. Maximum production as well as utilization of this renewable energy become a very popular topic from industry to academia. The distribution of renewable energy through the microgrid platforms and policy is one of the key factors which need to be introduced first [31]. A clear policy guideline from the regulators must incorporate for implementing the efficient and cost-effective distributed renewable energy system [32-33]. The scheduling and battery backup systems are highly recommended to introduce in the distributed energy management system [34]. Real-time, low-cost pricing policy, transparent, and traceable energy distribution are major concerns that need to be addressed [35]. The participants of the microgrid system and individual stakeholders should be aware of the benefits of using the microgrid system. Social-economic development and awareness creation among the consumers and stakeholders are also equally important and need to take into consideration before implementing the renewable energy system [36]. The energy distribution mechanism, microgrid distribution strategy, and supply and demand distribution policy are highly recommended to incorporate before establishing the energy distribution network [37].

4 Blockchain Application in Energy Trading Platform

The integration of blockchain applications with energy trading systems must have integrated the smart metering system in the network. The consumers, traders, and stakeholders should be connected to this network [38-39]. The smart meters are introduced to the power distribution system through a blockchain network which shows in figure 3. By using this network, it is easier to monitor the energy consumption and production capacity as well. All the data are encrypted and placed in the network through a smart contract [40].

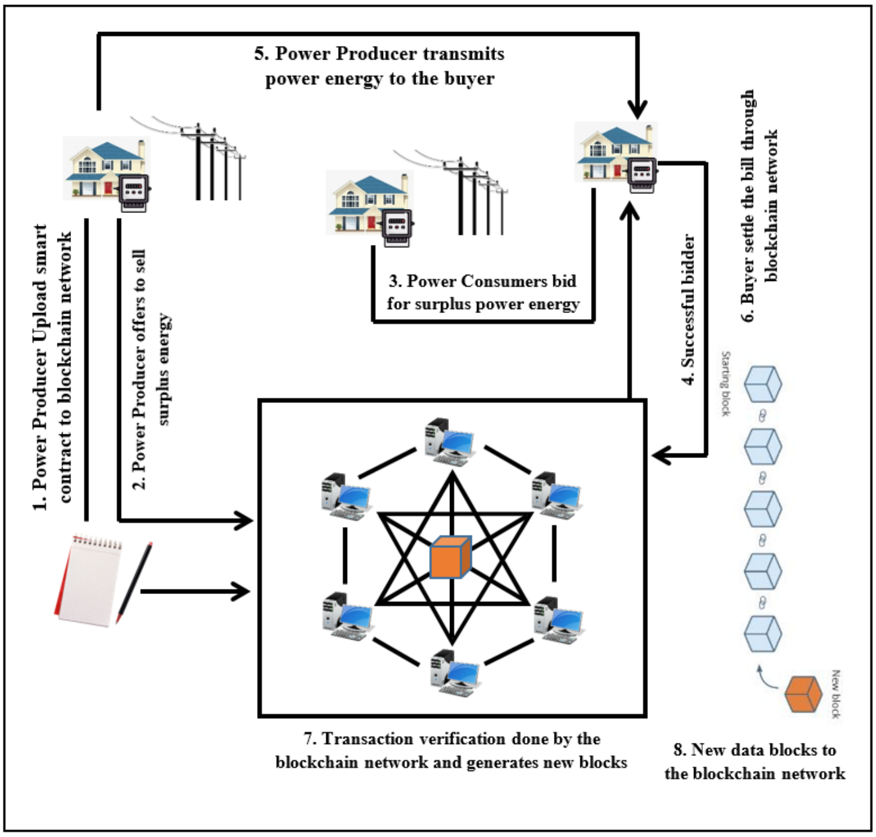

Figure 3: Power Energy Trading System

4.1 The Scope of Blockchain Technology for Distribution of Energy

(A) Renewable Energy Certificate and Wholesale Trading

Power producing companies should obtain these certificates from the related utility authority and all the companies must install the smart meters at their ends where they will communicate with other participants through the internet. These certificates will permit the energy producer to produce green energy and permission for the distribution of energy. Renewable Energy Certificate (REC) maybe play an important role to increase the investment in the field of distributed energy systems which may reduce the emission of carbon dioxide in the environment [41]. The integrated Demand Response System (DRS) is one of the more effective systems for the distribution of green energy where blockchain technology can be used for doing transactions between supplier and consumer [42].

(B) Transparency and security for distribution of Electrical Energy

Transparency, privacy, and security are always important aspects to grow the confidence between the consumers and distributors. To solve the privacy and transparency issues, the energy distribution system has been developed through a consortium-based blockchain trading system where all the connected nodes in this consortium received electricity from a large energy distribution grid [43]. Resiliency is another important aspect that needs to be addressed parallelly with privacy, especially when the live system goes down. The smart contract mechanism in the blockchain is an outstanding feature that can enhance privacy, transparency, and security issues [44].

(C) Electricity Trading Latency

Mostly, the efficacy of the energy distribution system depends on the latency when distributing energy from the main distribution grid to a remote location [45]. To solve this issue and improve the distribution and trading of energy, the blockchain-based application can use as a service platform that is capable to reduce latency and secure the transaction of power [46]. The Ethereum-based platform is suitable to support the energy distribution network to manage the local energy market where 600 participants belong to the consortium and the Ethereum protocol can process every transaction within 5 minutes and around 99% of computing power can be saved by using Proof-of-Stake consensus mechanism instead of Proof-of-Work (PoW) algorithm [47].

5 Blockchain Technology Implementation Challenges in Energy Sector

There are several steps have been emerged in the technology sector to address the issues, the researchers and business experts still face some challenges which are the below:

(A) Scalability

Tough blockchain and distributed ledger technology is the latest energy distribution platform, the transaction processing time has still become very high. Due to the design and the architecture of database sharing nature, the energy consumption for making a transaction is higher than any other centralized system [48]. For example, 0.001 kWh power is required for a transaction of Visa, whereas 740 kWh power is required for a Bitcoin transaction [49]. Although there is a significant number of methods have been proposed to enhance the transactional performance, every solution comes up with some limitations. Due to the sharing nature of the database, huge computational power and storage capacity are required to maintain the energy distribution network [48]. Sharing of the database is one of the big concerns of security issues which creates operational complexity in the consortium network [49].

(B) Regulation

Though a few numbers of regions like Japan and Europe have started to work on the regulation of blockchain technology, still it is in the premature stage [50]. The lack of global regulation is one of the main barriers to implementing the blockchain application in the field of distributed energy management systems [51]. A proper energy regulatory guideline is strongly required to maintain the distributed energy system which can assist to resolve the dispute management problem in the energy sector.

(C) Grid Infrastructure

To distribute renewable energy through a blockchain consortium network, a smart grid needs to be incorporated into the system. Still, maximum power distribution lines depend on the traditional grid. To minimize the electricity distribution cost, the system loses, and maximize the use of renewable energy; a large grid infrastructure setup needs to be established nationwide where the participants can be benefited from this infrastructure setup [52].

(D) 51% Attack

The 51% attack is another challenge in the blockchain that may interrupt the network operations [53]. Through these attacks, the hackers may take control of the network and can manipulate the transaction in their favor. Especially it is very risky for a small network where the number of participants is few. However, a 51% hash rate is not always a mandatory requirement to compromise a network, double spending attack can also be capable to comprise the same [54].

6 Distributed Energy Management with Ethereum Blockchain

Distribution of electricity management system through Ethereum Blockchain application depends on the smart contract algorithm, adaptability, and scalability as well [55]. The Ethereum-based blockchain architecture is a container-based model where all the codes are incorporated via a smart contract [56]. The electricity consumers, distributors, and energy producers relate to this Ethereum distribution network. By using the Ethereum Blockchain network, participants can share the data into the network and exchange digital transactions among themselves [57]. The stakeholders and energy distributors are also able to monitor the present status and additional energy requirements if needed. It is a public network where participants can share their information with their peers into the network. Distributed ledger system updates all the transactions and any changes in the network to the participants in the consortium which helps to mitigate the risk [58]. Ethereum blockchain network not only uses the smart contract but also shares the data through distributed ledger among the participants [59].

Ethereum consortium blockchain platform is a reliable and safe network for trading electricity between peer-to-peer (P2P) [60]. It is a highly secured network, and all the nodes are assigned with private and public keys, and transactions are encrypted through a cryptographic hashing algorithm [61]. The network also supports the credit type payment method which helps to provide a quick service for energy trading [62]. The identity of the user, electricity consumption, and billing status can easily monitor with incorporation between the smart meter and Ethereum blockchain network which will be the unique system in the energy distribution sector [63].

The Ethereum Blockchain consortium model will encourage the utility regulation sectors, the stakeholders, distributors, and energy consumers to distribute energy, especially for distributed energy trading systems where the network will introduce a secured transactional environment between the users.

7 Conclusions

Blockchain as an emerging technology that is introduced in distributed energy trading systems has been growing attention in the utility sector. There is remarkable scope especially in the energy sector to use this blockchain technology for the distribution of energy with high security, transparency, and privacy as well. The incorporation of smart contracts in the Ethereum blockchain network will be able to eliminate the operational complexity of the energy management system. Integrated Demand Response (IDR) will be a great example that will encourage to use of this technology for energy consumption and better energy management system with high efficiency. Despite the advantages to use this technology, some challenges need to be addressed especially regulatory issues before implementing the blockchain consortium network in the public sector energy platform.

Centralized and decentralized energy management system, smart microgrid, application of blockchain in energy trading platform, renewable energy, security, and transparency of energy trading are explained for the application of blockchain in distributed energy. To overcome the Blockchain implementation challenges in the field of the distributed energy system, a few numbers of important recommendations for future advancement of the blockchain application in the energy sector are highlighted as follows:

- Energy trading costs will be minimized by around 40% which will potentially reduce the consumers' billing costs by introducing the blockchain-based application.
- The end-users are connected directly to Ethereum based blockchain platform which allows them to buy the energy at the desired cost.
- To build a secure distributed energy system that is capable to increase the transparency of the stakeholders not compromising privacy.
- Ethereum blockchain uses Proof-of-Stake (PoS) consensus mechanism instead of a Proof-of-Work (PoW) algorithm which is capable to save around 99% of computing energy and is highly recommended for introduction in the field of efficient energy management systems.

However, the case study explains that the proposed system is capable to optimize the allocation of resources for the distribution of energy, reduce the system loss, and reduce the energy consumption cost of the users which means economically viable.

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