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Efficient Blockchain-Based Energy Auction Platform for Secured Energy Trading on Industrial Applications

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ABSTRACT

Electricity is vital for numerous aspects of human existence, including the operation of electronic devices and the maintenance of vital infrastructure. Even minor electronic devices and essential infrastructures cease functioning without electricity. The industrial and manufacturing sectors depend on a consistent and reliable energy supply because any mismatch between supply and demand can result in significant financial losses. Therefore, a solution is required to address the imbalance between energy supply and demand, particularly in the industrial sector. This study proposes a blockchain-based smart contract for energy auctions that will provide a safe and secure auction system with transparent and low maintenance costs referred to as gas costs, to enable industries to efficiently acquire energy from an energy supplier. The proposed smart contract is secure, effective, and user-friendly.

Key Words : Auction, Blockchain, Energy Trading, Industrial, Lightweight, Smart Contract.

Ⅰ. Introduction

Imbalanced electricity supply and demand can have detrimental consequences, from minor inconveniences to severe economic losses and extensive equipment damage. This can affect various sectors, from residential areas to heavy industries. Thus, an effective solution is required to evenly distribute electricity[1-3]. Several methods have been proposed, including microgrid and transactive grid energy trading[4,5], grid adequacy[6], energy auctions[5,7-9], and proper scheduling and demand response management[10,11]. However, ensuring consistent security is critical to their success.

Ensuring the security and reliability of energy trading platforms and networks is essential for ensuring proper energy distribution. The continuity of energy supply is crucial, as it maintains transaction platform security between buyers and sellers. Buyers must also be confident that their transactions are traceable and secure. In this context, blockchain-based platforms are a viable solution[5,7].

Smart contracts, which are precoded algorithms for blockchain networks, are tamper-proof and unchangeable, ensuring that energy transactions are secure and traceable[5]. The decentralized nature of the blockchain network guarantees that all entities have access to the same information, thereby ensuring transparency and reliability. Additionally, blocks of a blockchain provide information about transaction

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history, creating an immutable chain of blocks full of information used for traceability[12,13].

A blockchain-based energy auction platform can solve electricity supply and demand issues[5,7-9]. Buyers and sellers can securely and transparently conduct transactions, in contrast to decentralized networks, where all entities have access to the same information. Smart contracts ensure that energy transactions are tamper-proof and unchangeable, which is critical for proper energy distribution[5].

Owing to the advantages of a secured and reliable blockchain, in addition to the auction platform, it must also be implementable on other platforms in the industry. For example, a breakthrough technology of an electronic network that adopts a blockchain-based offline-online system[14], reinforcement learning using a blockchain for trusted solutions[15], distributed network-based audio copyright detection that produces accurate and reliable results[16], blockchain implementation on unmanned aerial vehicles (UAVs)[17], a practical voting system based on a blockchain[18], and a safe and practical art marketplace[19]. From an energy supply–demand distribution perspective, there are several energy distribution schemes in the form of blockchain-based microgrid energy trading, including those for electric vehicles[4,5]. Blockchain-based systems prove the positive characteristics of a blockchain as a new technology that plays an important role in the latest research.

A smart contract's unchangeable and static characteristics suit auction mechanisms with constant rules. Moreover, its implementation on the blockchain makes the auction platform transparent, providing a sense of equality and mutual security between suppliers and customers[20]. Therefore, the contributions of our study are as follows:

- We proposed a smart contract using an efficient algorithm for auction and buy-now mechanisms with handshake methods to ensure that the transaction process, from the start of the auction to the delivery stage, is properly completed.
- Using an efficient algorithm, the smart contract usage or processing cost, known as the gas cost, is minimized. This must not burden both the users with gas costs and the blockchain network due to inefficient algorithm inside the smart contract.

The rest of the paper is organized as follows: Section 2 discusses related works that support this study, Section 3 discusses the design and working-mechanism of the proposed smart contract system, Section 4 presents the results in the form of detailed gas costs required to operate the smart contract, and Section 5 summarizes the findings of the study.

Ⅱ. Related Works

This section explains the related works regarding energy distribution and the solution approach through a blockchain-based smart contract auction.

The issue of an imbalance between the available electric power supply and the power needed to operate, particularly in industrial areas, can result in significant losses. If the supply exceeds demand, wastage occurs. However, if demand exceeds supply, especially during critical times, it can lead to severe losses for the industrial sector.

There are diverse solutions to address the problems of power supply-demand imbalance in industrial areas. One effective approach is based on game theory scheduling on smart grids, as demonstrated in research A. This approach has shown promising results in reducing peak-to-average ratio of total energy demand and costs, as well as optimizing energy charges for individuals on a daily basis[10].

Other solutions include using a Demand Response (DR) program in a multi-energy industrial park[8]. The result shows the DR programs effectively reducing tie line power in the industrial area. Another approach is an electricity trading system implemented on electric grids, known as a transactive grid, or its implementation on microgrids[4,5]. The two energy trading on grids shows the result of maximising the available supply on one grid to make its seller's revenue and providing trusted and secure settlement for electricity trading transactions.

Another solution approach is, of course, energy trading via a blockchain-based auction mechanism[3]. Decentralized nature increases security and efficiency and minimizes losses that occur when long transmissions occur[6]. Moreover, the energy trading via auction scheme is also connected to Electric Vehicles (EV); compared to non-blockchain, this blockchain-based solution has high reliability, scalability, and improved cost-efficiency[9].

The uniformity of results across related research indicates that blockchain-based solutions for energy trading offer consistent benefits, such as enhanced security, efficiency, and cost effectiveness. These findings underscore the potential of blockchain technology as a viable approach for improving energy trading systems in various contexts.

Ⅲ. Proposed System

This section discusses the developed smart contract system, which uses an auction approach for electrical energy transactions on the blockchain network.

The proposed smart contract is designed as the primary technology to serve as a platform for user transactions. In this article, the smart contract serves as an electrical auction platform, represented in Figure 1, that allows enterprises or industries with a high demand for electrical power to purchase through safely auction platform use this smart contract. A smart contract consists of several functions that work in synergy with each other so that a transaction can finally be carried out; these functions are as follows,

- **RegisterSeller**: In order to prevent dishonest distributors from negatively impacting the user experience on the platform, electricity suppliers or distributors are required to register their specific industrial data or company information as legitimate electricity suppliers.
- **Authorized**: This function provides access to legal suppliers for trading on the built smart contract auction platform can only be used by smart contract authorities.
- **ListingEnergy**: Suppliers must register the electric power they intend to sell on the smart contract, which initiates an auction process with a unique ID assigned to each sale. This unique ID allows the sale to be visible to all users, and buyers can access detailed information about the sale and place

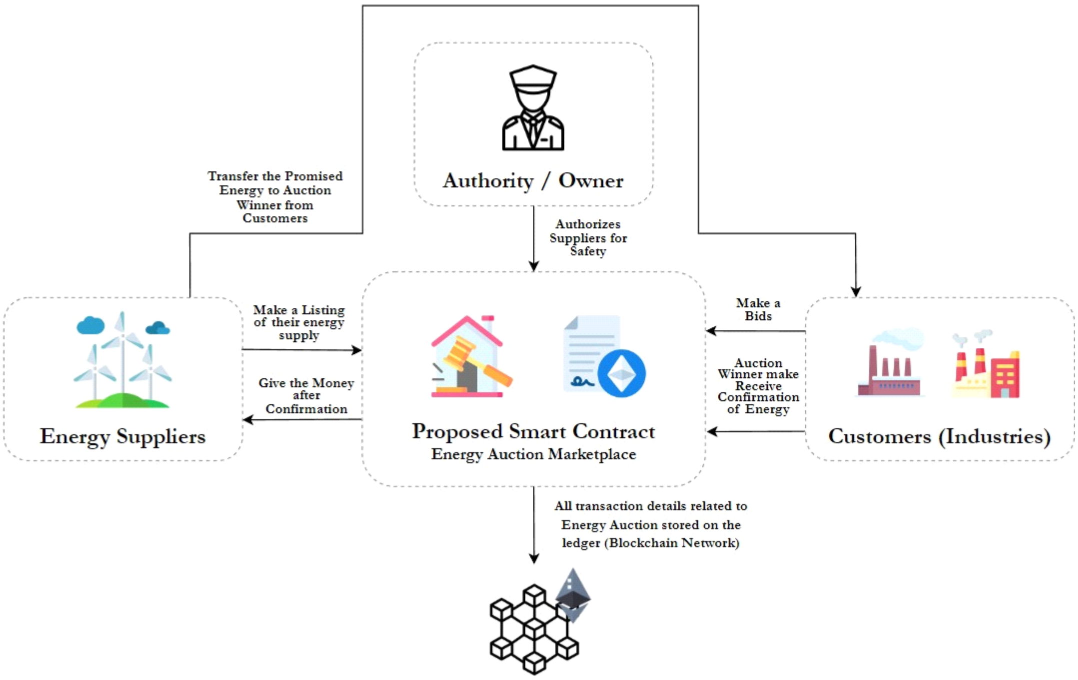

Fig. 1. Architecture Diagram of Proposed Energy Auction Platform.

bids through the unique ID.

- **SubmitBid**: The function allows users to register their bids for the electric power listed on the smart contract, which can be accessed through the unique ID assigned to each sale, as depicted in Figure 2. The algorithm facilitates the submission of bids by customers for the sale they wish to purchase.
- **BuyNow**: This function serves as an alternative method for purchasing electric power that is sold through smart contracts. In certain sales, the seller may set a fixed price, allowing buyers to directly purchase the power without going through the auction process.
- **AuctionClose**: The seller can utilize this function to stop the ongoing auction process for the electricity being sold. Once the auction is closed, other buyers are no longer able to place bids on the sale, and the final bid becomes the winning bid for the electricity.
- **ReceiveConfirmation**: After the successful purchase of electricity through the auction process or direct purchase, the buyer will receive the electricity as per the bid or buy now terms. Once the buyer confirms the receipt of the electricity,

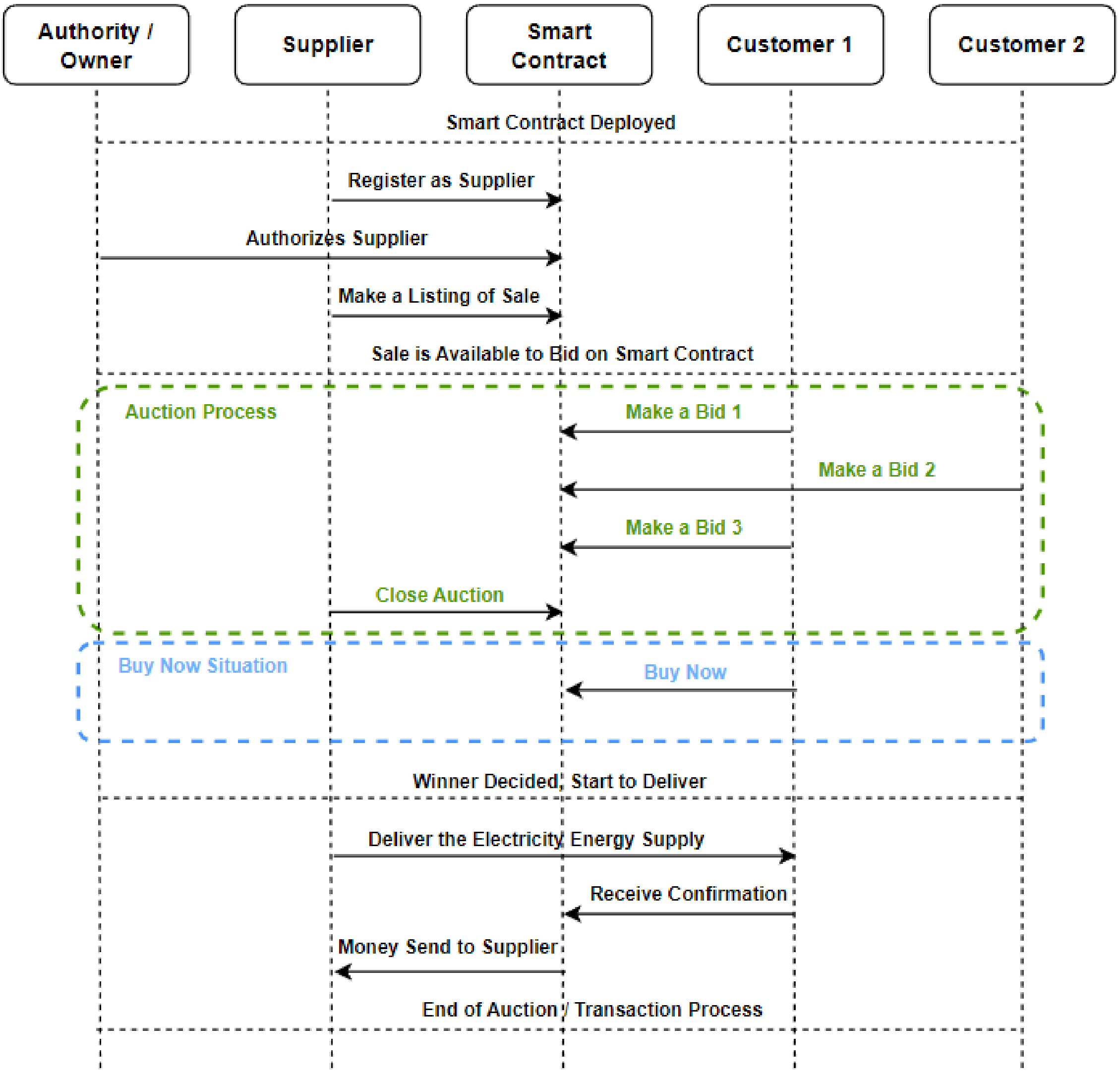

Fig. 2. Transaction Flow of Proposed Smart Contract.

the payment registered via the bid or buy now function will be automatically transferred from the smart contract to the seller, ensuring secure and transparent transaction between buyers and sellers, eliminating the possibility of fraud.

To conduct a transaction in the form of an electric power auction, represented in Figure 2, the seller must register his electric power supply company's information as a legal supplier; in registration, the supplier uses the **RegisterSeller** function in the smart contract. Then, each supplier's information will be checked for legality and credibility by the authorities, who also act as the owner of the smart contract. If the supplier who registers is eligible to join this energy trading platform, the seller can register his electricity supply to start auctioning and selling it.

A verified supplier registers an electricity supply for auction using the **ListingEnergy** function, along with detailed information such as the electric power supply being sold, the period for the electricity supply to be sent to the customer, the initial auction price, the buy-now price if the supplier desires the buy-now feature. If the supplier does not include a buy-now price, it will be listed as a sale that cannot be purchased directly, or the buy-now feature will be disabled. Each sale registered by the supplier will have a unique ID in the form of numbers used for suppliers and buyers to access each sale in the smart contract.

Algorithm 1: Submit Bid Function

input : ID Number (Energy Listing), Bid Price, Supplier's Blockchain Address, Customer's Industry Address
output: Auction Winner's Blockchain Address, Winner's Industry Address

Require:
- *Energy.Number* == ID Number;
- *Energy.Supplier* == Supplier's Blockchain Address;
- *Energy.BuyNow* == **False**;
- (*Energy.CurrentPrice* + *Energy.MultiplicationPrice*) ≤ Bid Price;

if *Require* ***Passed*** **then**
    Energy.WinnerAddress ← Customer's Industry Address;
    Energy.CurrentPrice ← Bid Price;
    Energy.ReceiveConfirmed ← **False**;
    Energy.AuctionClosed ← **False**;
else
    Revert state and show error;
end

In this smart contract, each buyer does not need to register with the smart contract to access and bid on the available electricity sales. When a buyer wants to bid, the buyer can access the electricity sale using the unique ID. To place a bid, a buyer, through the **SubmitBid** function, must input a bid price greater than the bid available at that time, plus the multiplication prices listed by the previous supplier. Buyers can also use the **BuyNow** function, when available, to buy directly without the need to carry out the auction process and the address or industrial address to which electricity is sent if the auction is successful as the winner or if buyers use the buy-now feature. Each submitted bid money will be stored first in the smart contract; if a larger bid beats the current bid, the money will return to the buyer's online wallet according to the wallet address.

Ⅳ. Results and Analysis

This section explains the traceability and security aspects adopted from smart contracts built and functioning on the blockchain network and efficiency aspects by showing detailed Gas Costs as operating costs for each function in the smart contract.

The smart contracts were built using solidity computer language through Remix IDE code editor and deployed and functioned on several ethereum blockchain-based networks, such as the Goerli test network with consensus Proof of Authority (PoA) and Remix VM London, especially when testing the functionality of smart contracts and ensuring that each function functions properly. In detail, here are the addresses used on Goerli test network stated on Table 1.

Table 1. Users address from Goerli test network

Role	Address
Owner of Smart Contract	0x9d4B7eE6c2aCFD708CB5aA6fA3e60341466b889a
Supplier	0x3A76f6b1225b40A370981120EB1E664bb6F2ec5d
Buyer 1	0xE86E3717254968Df90B64612e423A00eAEF4b36d
Buyer 2	0xeCC0b0E2959F4958B06eC9d3911aC1326d15cF54

Table 2. Detailed Usage Cost Information of Proposed Smart Contract.

Functions	Function Caller	Gas Used (Gas)	Average Cost (ETH)
Smart Contract Deployment	Authority / Owner	2445481	0.0349704
Register as Energy Supplier	Supplier	98017	0.0014016
Authorize Energy Supplier	Authority / Owner	35178	0.0005030
Make a Listing of Energy	Supplier	209128	0.0029905
Submit Bid	Customer	140502	0.0020092
Buy Now	Customer	110692	0.0015829
Auction Declared End	Supplier	40948	0.0005856
Receive Confirmation	Customer	36981	0.0005288

4.1 Traceability

With a smart contract based on the blockchain network, every information and transaction that occurs through the smart contract will be recorded and stored in a chain block. Every activity that occurs through the functions in the smart contract has a hash transaction that can be reviewed for details so that every transaction that occurs through a smart contract, including this proposed smart contract, becomes traceable. Especially in this smart contract, the registration of supplier information allows for tracking and proving the supplier's validation as its legitimacy as a trusted supplier, Essentials for convenient trust between industries as the customer, auction platform, and the energy supplier[12,13].

4.2 Security

Fundamentals from the security aspect are, of course, also influenced by the traceability of the system. Achieving good security, especially on a platform with transactions with a sizable amount of money, requires efficient auditing data to achieve accountability for every transaction between suppliers and customers. In addition, smart contracts are constant, and their contents cannot be changed after being deployed on the blockchain network, so security against hacking of the smart contract algorithm cannot occur[12,13].

Then, where each participant who joins in a transaction cryptographically signs every transaction that occurs; in this case, intruders who want to or history can be prevented because they do not have a private key, which is very closely related to the Man in the Middle (MITM) attacks. Furthermore, every transaction that is directly recorded on a block on the blockchain is impossible to duplicate or imitate due to the decentralized nature of the blockchain by spreading all the information on each node so that if an anomaly occurs due to differences in duplicated data, it will be immediately discarded, making blockchain-based systems with strong data integrity or non-repudiation and resistance to Replay Attacks[12,13].

4.3 Efficiency

In a smart contract that is built on several functions, each user does not need to use each function to be able to carry out electricity transactions. As can be seen in Table 2, each function only needs to be used by certain users, thereby reducing operational costs for users to smart contracts. Each function also has operational costs, namely gas costs, that vary.

The usage or processing cost, usually known as Gas Cost, in each function of a smart contract is primarily influenced by the complications of the algorithm in it, such as the number of iterations of loops, data structures that are stored in stacks, and other complications that can cause a function to have a high Gas Cost, which can result in heavy transactions on the network, as well as burdens fees to be paid by smart contract users is high.

The Gas Cost in each function is relatively unchanged whether it is used for the first time or the tenth time, but there are several functions whose gas value changes if they have a data structure that accumulates a lot and is not efficient. In calculating Gas Cost, the units used are Gas and Ether (ETH), where ETH can be converted into GWei and Wei, but in general, ETH is more popular and easy for users to understand. Gas Cost in ETH is calculated based on the value of Gas converted to ETH, with a choice of **Average** transaction speed or priority, as of March 21, 2023, at 14.3 GWei for every 1 Gas, Average speed or priority[21].

The proposed smart contract for auction energy trading is compared to related work based on a similar concept. Table 3 compares the Gas Cost for each complete auction transaction to demonstrate the efficiency of the proposed smart contract. The table shows that the proposed smart contract allows multiple users to simultaneously make an auction sale and transaction on the same smart contract. This method saves gas because the smart contract only needs to be deployed once and can be used for multiple transactions. By contrast, the related work's algorithm necessitates the deployment of a smart contract each time a new auction request is made, resulting in higher deployment costs[3].

Furthermore, the algorithm in the related work only allows for one transaction per smart contract, with no function to begin a new sale using the same smart contract. On the other hand, the proposed smart contract allows energy suppliers to make a new sale after some auction is completed, which is more efficient on Gas Costs. The **SubmitBid** function of related work is calculated as the average of four times bidding Gas Costs, which are stated as 87221, 57211, 42221, and 42221; thus, we take the average Gas Cost from related work's four bid function costs. On the other hand, the proposed smart contract is more efficient because it allows for multiple transactions without the need for repeated smart contract deployments[3].

Overall, the proposed smart contract for auction energy trading is more efficient than the related work's smart contract-based auction energy trading. This is due to its ability to handle multiple transactions without repeated deployment, resulting in lower Gas Costs per complete auction transaction. Implementing a concise and efficient algorithm, which is one of our goals and contributions to this system, can create smart contracts with relatively low-cost functions without reducing the functionality of the electricity auction transaction while still maintaining maximum security.

V. Conclusions and Future Work

The importance of energy stability, particularly electrical power, between the consumed power and the existing supply in the industrial sector significantly influences various important factors, from minor component damage to critical financial conditions. Buying through a trusted and safe auction system is

Table 3. Usage Cost (Gas) Efficiency Comparison against Related Work [3]

Functions (This Study)	Usage Cost (Gas)	Usage Cost (Gas)	Functions (Related Work)
Make a Listing of Energy Submit Bid Buy Now Auction Declared End Receive Confirmation	209128 140502 110692 40948 36981	1520051 57218	Listing and Start Auction Submit Bid (Average)
Total Usage Cost (Gas)	538251	1577269	

an effective way to balance energy requirements and supply. Blockchain-based auction platforms can provide security from the perspective of decentralized and traceable blockchains. An auction system in the form of a smart contract, whose characteristics are static and cannot be changed, supports a fair auction system for customers and suppliers. Blockchain-based smart contracts that operate safely and efficiently were built with a concise algorithm without reducing the functionality. The designed system has a relatively low gas cost.

This study can serve as a foundation for future research on the topic, using new technologies, such as non-fungible tokens as electronic certificates for suppliers, which can increase the platform's credibility and provide more trust from the industry side as customers.

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