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An Anti-fraud Double Auction Model in Vehicle-to-Vehicle Energy Trading with the K-factor Approach

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***Abstract*—The rise in electric vehicle adoption has reduced greenhouse gas emissions in transportation but overloads the power grid due to charging demands. This paper introduces a Double Auction (DA) model in Vehicle-to-Vehicle (V2V) energy trading with the K-factor approach. The novel approach defines unique market clearing prices for each successfully matched V2V transaction pairs, robustly counteracts potential economic fraud. It overcomes shortcoming of some other models of sacrificing participants who could have conducted V2V transactions in order to prevent economic fraud. Meanwhile, the model ensures transactional economic benefits, transparency and fairness. This work facilitates EV adoption across the UK and globally, by increasing confidence and convenience in energy trading mechanisms.**

Keywords—V2V energy trading, electric vehicle, double auction, k-factor.

I. Introduction

While with the rapid development of energy harvesting and information communication technologies (ICT), more and more distributed energy resources (DERs) are integrated into smart grids [1]. Electric Vehicles with surplus energy might have offered more roles to the EV owners to participate in energy trading, whom not just energy consumers, but also prosumers [2]. With V2X functionality [3] (e.g. vehicle to grid (V2G), vehicle-to-building (V2B)), EV owners are now able to undertake control actions to manage their daily energy consumption and generation [4].

In this context, the vehicle-to-vehicle (V2V) energy trading has been considered to be an efficient method to implement local EV energy trading. To establish a reliable V2V energy trading platform, numerous research studies have focused on developing pricing algorithms for energy trading [5-10]. A prominent trading algorithm, the Double Auction (DA), has been introduced and widely adopted due to its transparency, fairness in the trading process, and economic benefits. The works in [5-7] employed the double auction with an average mechanism as their pricing method to set up energy trading platforms. In [5], a platform for the transactive energy market is presented, aiming to maximize the welfare of all market subscribers by enabling competitive energy trading. The study in [6] introduces a model detailing the complex decision-making processes for energy trading among multiple Plug-in Hybrid Electric Vehicles (PHEVs), utilizing non-cooperative games and double auctions. Meanwhile, [7] presents a P2P energy trading platform that leverages iterative double auction (IDA) and block chain technology to extract hidden information from all participants, aiming to achieve maximum social welfare. However, a notable concern with the average mechanism employed in these studies is the potential for economic fraud. Due to the vulnerability in the average mechanism, sellers might manipulate the clearing price by falsely reporting the amount of energy being traded in order to satisfy their own advantage.

To address this problem, another mechanism to determine the clearing price, known as the trade reduction mechanism, has also been widely incorporated into double auction models. In [8], a multi-unit double auction model is proposed that facilitates online energy trading. The research in [9] presents a block chain-enhanced double auction model for energy trading, which minimizes energy losses from extended transmissions. Importantly, the computational overhead from incorporating block chain is negligible in this model. Meanwhile, [10] offers a double auction-based, game-theoretic approach to P2P energy trading, ensuring that participants' economic benefits and private information are safeguarded. While the trade reduction mechanism effectively addresses the economic fraud issue, it comes at the cost of forgoing a transaction between a matched buyer and seller who could have otherwise engaged in V2V energy transactions.

In response to these challenges, this paper proposes an advanced double auction model for V2V energy trading, utilizing the k-factor rule as the decision mechanism for determining the clearing price. Unlike traditional models where all participants share a single market clearing price, the adoption of the k-factor rule establishes unique market clearing prices for each successfully matched transaction pair engaged in V2V energy transactions. This effectively addresses the economic fraud issue and eliminates the need to sacrifice matched transaction pairs. Additionally, the double auction model safeguards participants' economic interests and balances the supply-demand relationship in the local energy market. This model supports the realisation of V2V energy trading in local energy markets and potentially reduces energy costs for EV drivers.

II. METHODOLOGY

2.1. Double Auction Model in V2V Energy Trading

The V2V energy trading platform aggregates data from buyers (EV owner with energy demand) and sellers (EV owner with energy supply), employing the Double Auction (DA) method to finalize transaction pairs. The DA mechanism facilitates transactions involving multiple buyers and sellers [11]. Participants submit their reservation bid and ask prices to the platform, which then determines the clearing price by aligning their requirements. Given its capacity to accommodate multiple stakeholders, the DA mechanism is particularly apt for situations with numerous buyers and sellers.

V2V energy transactions occur within the local energy market at scheduled time slots. Participants can access transaction specifics, like the clearing price, energy volume, and trading location, via the platform. Moreover, they can adjust these details prior to the closure of each trading cycle, allowing them to maximize economic returns through strategic auctioning. If energy quantities are imbalanced or bid/ask prices are incongruent, the trading process will be unsuccessful. In such instances, EVs resort to charging directly from the power grid. A platform fee is levied on each successful V2V transaction, covering setup and upkeep expenses. Fig. 1 illustrates the architecture of the proposed V2V platform.

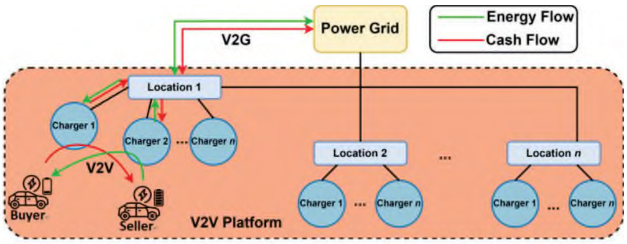

Fig.1. Architecture of V2V Energy Trading Platform

Let $L = \{1, 2, 3, \dots, L\}$ denotes the set of participants in V2V energy market, where $L \triangleq |L|$ represents the total number of participants. The energy buyer set is denoted by B with index $n \in B$, and the energy seller set is denoted by S with index $m \in S$, where $B \triangleq |B|$ and $S \triangleq |S|$ represent the number of energy buyers and sellers, respectively. Assuming that all participants in the V2V energy market is either energy buyers or sellers, in the same trading time slot, we have $(B \cup S) = L$ and $(B \cap S) = \emptyset$.

To find out the market clearing prices of multiple buyers and sellers, reservation bid of buyer n at time slot t (R_{bn}^t) and reservation ask of seller m at time slot t (R_{sm}^t) will be sorted following natural ordering rule:

$$R_{b1}^t \geq R_{b2}^t \geq R_{b3}^t \geq \cdots \geq R_{bn}^t \tag{1}$$

$$R_{s1}^t \leq R_{s2}^t \leq R_{s3}^t \leq \cdots \leq R_{sm}^t \tag{2}$$

The reservation bids from buyers are sorted in a decreasing order, while the reservation asks from sellers are sorted in an increasing order. To address scenarios where multiple buyers/sellers submit identical reservation bids/asks simultaneously, participants are ranked chronologically, ensuring that those who submit their bids/asks earlier are given priority.

The price curve, derived from the sorted reservation bids/asks, is termed the buyer's or seller's curve, as depicted in Fig. 2. The point where the two curves intersect designates the trading clearing point, represented by the cross in Fig. 2. Transactions to the left of this point are successfully executed V2V transactions. In contrast, participants on the right side of this point fail to transact due to mismatched asks and bids. Suppose the buyer at this trading clearing point is denoted as bx, and the corresponding seller as sy. At this intersection, two possible scenarios arise, which are:

$$Case\ 1: R_{bx}^t \geq R_{sy}^t \tag{3}$$

$$Case\ 2: R_{bx}^t < R_{sy}^t \tag{4}$$

These two cases describe the conditions of the last successful reservation, which not affects the trading process. The following chapter will take Case 1 as example.

2.2. Economic Fraud Problem in Average Mechanism

In average mechanism, all matched participants at time slot t will share the same market clearing price which will be denoted as:

$$P^t = (R_{bx}^t + R_{sy}^t)/2 \tag{5}$$

However, this method does have a loophole and could potentially lead to economic fraud activities. In a practical market scenario, buyers typically demonstrate a tendency to accurately disclose their desired quantities while actively pursuing competitive pricing. Conversely, sellers are incentivized to deliberately underestimate the quantities they possess in order to constrict the available supply and thereby elevate the market price. As shown in Fig. 2, assuming that, seller 1 underreport the energy supply amount from α down to β, and this causes the sellers' curve shifting to left. In this case, the new market clearing price will be price 2, and the difference between middle price 1 and 2, γ, will be the extra profit seller 1 obtained by manipulating the market [12].

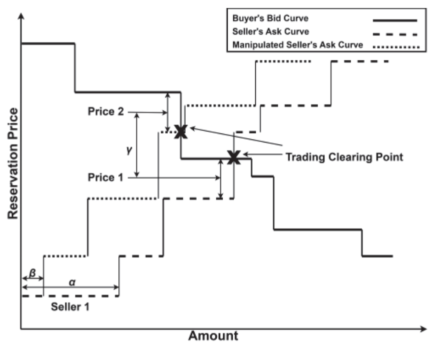

Fig. 2. Economic Fraud Problem in Average Mechanism

2.3. Transaction Pair Sacrifice in Trade Reduction Mechanism

To tackle this issue, many double auction models have adopted an alternative mechanism called the trade reduction mechanism first proposed in [13] to determine the clearing price. Similarly, all matched participants at time slot *t* share the same market clearing price in trade reduction mechanism. To prevent economic fraud problem, the matched bx and sy will be sacrificed, and only the first $x-1$ of buyers and $y-1$ of sellers could conduct V2V energy transaction. The determination of market clearing price is more flexible, that any value between R_{sx-1}^t and R_{bx-1}^t is allowed:

$$P^t \in [R_{sx-1}^t, R_{bx-1}^t] \tag{6}$$

For convenience of illustration, in Fig. 3, the market clearing price is determined as $P^t = R_{sx-1}^t$.

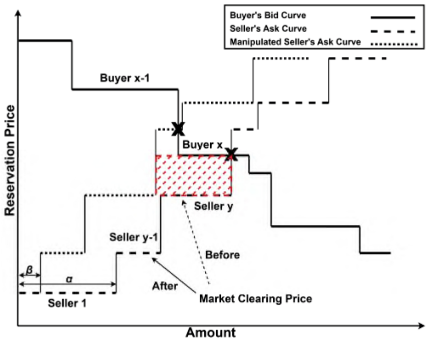

Fig. 3. Participants Sacrifice in Trade Reduction Mechanism

Given that Seller 1's supply cannot fluctuate without bound, the trade reduction mechanism significantly mitigates the risk of economic fraud by obfuscating supply details. However, the drawback of forgoing a potential V2V transaction between a matched pair of participants is considerable.

2.4. K-factor Rule Based Pricing Mechanism

Rather than using above mechanisms where all participants adhere to a unified market clearing price, the adoption of k-factor rule in the model assigns distinct market clearing prices to each successfully paired transaction in V2V energy exchanges, and hence eliminates the possibility of economic fraud by concealing energy amount and manipulating market clearing price. In this process, no matched transaction pairs will be sacrificed.

The rule is expressed in (7). In this equation, P_n^t and P_m^t stands for the market clearing price of matched transaction pair buyer n and seller m, k is the pricing factor.

$$P_n^t = P_m^t = k \cdot R_{bn}^t + (1\text{-}k) \cdot R_{sm}^t \tag{7}$$

When $k = 1$, the market clearing price matches the buyer's bid price, effectively granting the buyer the privilege of setting the bid, while the seller can either accept or decline the trade. Conversely, with $k = 0$, the seller has the prerogative, and the market clearing price is set at the seller's ask price. For $k = 0.5$, the rule calculates the final trading price by averaging the bids from both parties, ensuring that both the buyer's and seller's offers equally influence the trading price [12]. Implementing the k-factor rule allows the platform to equitably calibrate prices between buyer and seller markets.

The energy bill of buyer n trades with seller m at time slot *t*, $B_{n,m}^t$, is defined as follow:

$$B_{n,m}^t = \begin{cases} (1+\eta_b) \cdot (x_{n,m}^t \cdot P_n^t), & if\ V2V\ transaction \\ 0, & otherwise \end{cases} \tag{8}$$

$$B_{m,n}^t = \begin{cases} (1-\eta_s) \cdot (x_{m,n}^t \cdot P_m^t), & if\ V2V\ transaction \\ 0, & otherwise \end{cases} \tag{9}$$

Similarly, the energy bill of seller m trades with buyer n at time slot t is denoted by $B_{m,n}^t$. Where $x_{n,m}^t = x_{m,n}^t$ is the energy amount traded between buyer *n* and seller m. η_b is the buyers' charging transaction fee ratio, and η_s is for sellers.

The total tariff of buyer *n* (seller *m*) at time slot *t* is represented by C_n^t (C_m^t):

$$C_n^t = \sum_{m=1}^{M} B_{n,m}^t + (Q_n - \sum_{m=1}^{M} x_{n,m}^t) P_{BFG} \tag{10}$$

$$C_m^t = \sum_{n=1}^{N} B_{m,n}^t + (Q_m - \sum_{n=1}^{N} x_{m,n}^t) P_{STG} \tag{11}$$

where Q_n (Q_m) indicates the energy demand (supply) of buyer n (seller m) in time slot t. P_{BFG} (P_{STG}) is the energy price that buy from (sell to) power gird.

III. Case Study

A case study was conducted between the trade reduction mechanism based DA model and proposed k-factor based DA model to make a comparison of the economic benefits, utilizing historical EV data sourced from a public car park in England, UK. In total 20 EVs were chosen as participants, split evenly between 10 buyers and 10 sellers. The residual electricity was measured using on-board sensors. The P_{BFG} is fixed at £0.15/kWh and P_{STG} is £0.05/kWh. And the transaction fee is ignored as it does not affect the final result. By randomly generating reservation bids and asks, the dataset for the case study was formulated, as presented in TABLE I.

TABLE I. The Data In Case Study

ID	Buyer		Seller	
	Reservation Bid (£/kWh)	***Demand (kWh)***	***Reservation Bid (£/kWh)***	***Supply (kWh)***
1	0.094	8.0	0.010	15.6
2	0.126	10.3	0.159	4.7
3	0.080	10.3	0.080	10.9
4	0.100	7.0	0.102	5.0
5	0.116	15.5	0.108	11.2
6	0.125	5.5	0.125	10.7
7	0.115	14.9	0.140	4.7
8	0.112	9.5	0.085	11.8
9	0.105	14.4	0.077	6.5
10	0.087	15.7	0.095	10.2

And the bid and ask curves are shown in Fig. 4.

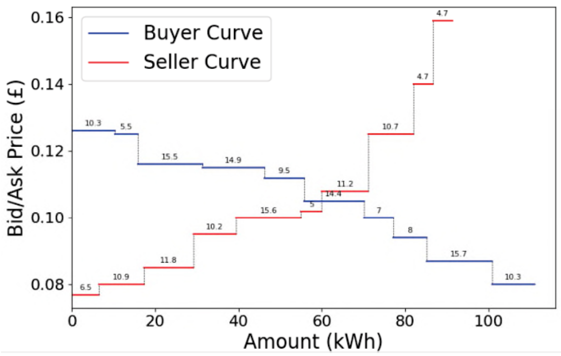

Fig. 4. Bid and Ask Price Curve

IV. Results and Discussions

The comparison of energy bills between the two mechanisms: the trade reduction mechanism based DA model and the proposed k-factor based DA model are illustrated as follows. The buyers' energy bills are shown in Fig. 5.

Fig. 5. Buyers' Energy Bills Comparison

Fig. 5 shows that in both models, buyers can achieve better economic benefits than direct transactions with the power grid. Buyers 1, 4, and 10, who failed to find matches and conduct V2V energy trading in the DA, had to trading with the power grid. Buyer 9, while succeeding in the k-factor based DA model, was the sacrificed entity in the trade reduction mechanism based DA model, hence can only interact with the grid. Notably, even when both models engage in V2V transactions, there's a slight difference in the bills due to distinct market clearing prices in the two models. Specifically, the trade reduction mechanism based DA model has a fixed market clearing price at R_{sx-1}^{t}, this clearing price is a buyer-friendly price in transactions and resulting in a marginally lower energy bill compared with the bill of the k-factor based DA model.

Fig 7. presents the incomes for selling energy for both models.

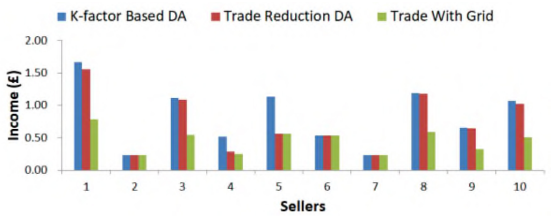

Fig. 6. Sellers' Energy Bills Comparison

Likewise, for sellers' energy bills in both models, V2V transactions offer greater income than selling directly to the grid. Sellers 2, 6, and 7 couldn't find matches for V2V transactions, hence their energy supply are transacted to the grid. Seller 5, the sacrificed entity in the trade reduction mechanism based DA model, doesn't benefit as much as in the k-factor based DA model. The earnings of sellers engaging in V2V transactions differ slightly between the two models due to their respective market clearing prices. Since the market clearing price in trade reduction mechanism based DA model leans towards benefiting buyers, the sellers' revenue in Model B is marginally less than in the k-factor based DA model.

V. Conclusion

The paper proposed a V2V energy trading model utilizing DA, enhanced by the k-factor rule. Unlike most conventional pricing mechanisms which allow all participants in V2V to share the same market clearing price, the adoption of the k-factor rule assigns unique market clearing price for each successfully matched energy trading pairs. This innovative approach not only eliminates the risk of economic fraud where certain sellers adjust their energy supply submissions to manipulate market clearing price for their own profits, but also addresses a shortcoming in other models that avoid economic fraud by sacrificing certain successful V2V matches. Furthermore, the model offers significant economic advantages to all energy participants compared trade directly with power gird, while ensuring transactional transparency and fairness.

VI. Acknowledgment

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