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Review article

Operation of distribution network: Challenges and opportunities in the era of peer-to-peer trading

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ABSTRACT

In recent years, the attention of researchers has been drawn to identifying and investigating new optimal approaches for operation of the distribution networks (ODNs) and the role of various players including distribution system operators in ODNs. This attention is due to the expansion of distributed resources changes in the role of end consumers and the expansion of local markets such as peer-to-peer (P2P) trading. Therefore, the challenges related to ODN seem important now, taking into account the changes in the current distribution networks compared to the past, the most important of which is the change in the role of consumers to prosumers and the creation of P2P trading. Hence, in the paper, a review of the effective features in ODNs such as network reconfiguration, mobile energy storage systems, and energy markets is presented, and then the new role of players in ODNs is explored, focusing on P2P trading features. Also, in this paper, we have categorized the challenges of ODN optimization with P2P trading and we have identified the limit behavior modeling of prosumers and policy schedule as research opportunities, and we have given sufficient insights to the researchers by examining them more deeply.

1. Introduction

The power grid has traditionally consisted of several large-scale generating units and an extensive interconnected network that transmission and distribution electrical energy to a range of residential, commercial, and industrial consumers. The distribution networks (DNs) are the final part of the power grid, which are responsible for supplying electricity to the end consumers with optimal operation. The operation of the DN (ODN) is known as one of the main challenges of the DNs (Ruan et al., 2022). The main goal of ODN is to supply the electrical energy demanded by consumers, with maximum reliability and quality, and minimum cost, which is managed by the distribution system operator (DSO) (Jayachandran et al., 2022). Therefore, ODN is basically an optimization problem with a variety of objective functions, decision variables, and constraints. Decision variables such as (i) network reconfiguration (NR), (ii) mobile energy storage systems (ESSs), and (iii) energy market have a great impact on optimal ODNs. On the other hand, as summarized in Table 1, the DNs have undergone significant changes over the years, which have led to changes in the ODNs. Thus, we first review the characteristics of the DNs and then discuss how ODNs function with NRs, mobile ESSs, and energy markets. Finally, given the growth of peer-to-peer (P2P) trading in the DNs and the need for significant change in the operation of the ODNs, we review recent literature on P2P trading and then discuss future challenges and opportunities.

The energy market is known as the first and most traditional decision variable in the ODNs. The integration of distributed energy resources (DERs) and the expansion of local markets (LMs) in DNs have led to a transformation in the ODNs because the expectations and the way consumers interact with the DNs will have changed. In traditional DNs, the DSO buys energy from the upstream network and delivers it to consumers at fixed prices (Tofighi-Milani et al., 2022). With the presence of DERs in traditional DNs, it is possible for the DSO to reduce costs by aggregating DERs. Therefore, in this case, the DSO optimizes the ODN by trading with the owners of DERs. In this regard, in Jiang et al. (2022) the coordination of the day-ahead market and DER with the aim of optimizing ODN is proposed. In Ravi et al. (2022) the ODNs with wholesale and reserve markets in the presence of the DERs have been done. In Chen et al. (2022a), the impact of DERs uncertainties on the ODNs has been investigated. On the other hand, the LMs are defined as tools for adjusting generation and consumption patterns in

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Table 1
Summary of changes in the DNs.

	First generation	Second generation	Third generation	Fourth generation
Property	radial structure with unidirectional flow direction	expansion of the DERs	expansion of aggregators and microgrids	expansion of the prosumers
Players	as the owner, the DSO manages the DN	energy trading between DER owners and DSOs	reducing the authority of the DSO and increasing the role of	increasing the role of consumers and changing their behavior
Instrument	the energy at a fixed price buying energy from the upstream network and using static NR	Dynamic NR considering DER	aggregators and microgrids energy trading in the LMs and expansion of mobile ESSs	P2P trading

response to a price signal to help optimize the ODNs (Suryakiran et al., 2023). In other words, the DSO should increase coordination with the LMs players such as microgrid operators (Armioun et al., 2023), virtual power plant operators (Zhang et al., 2022), and aggregators of the DERs (Honarmand et al., 2021). For example, in Du and Li (2019), based on neural networks, the coordination between microgrid operators and the DSO is modeled. In Mousavi and Wu (2021), considering several aggregators of DERs, a coordinated ODN with the upstream network is proposed. In Ullah and Park (2022b), the ODN is proposed by considering the coordination between the DSO, the transmission network operator, and the aggregator of the DERs.

The NR is another decision variable for the DSO in the ODN, which has received much attention in recent years. A DN usually operates in a radial topology, meaning that each node has exactly one path to the slack node. Switches in a DN can be divided into two types: tie switches normally open and sectionalizing switches that are normally closed (Zhan et al., 2020). NR is one of the functions of DN automation that improves the ODN by changing the structure (Yue et al., 2023). The NR methods are divided into two categories: the static and dynamic NR (Taghavi et al., 2023). The static NR examines the best configuration for annual, seasonal, monthly, and weekly periods, while the dynamic NR is often proposed for short periods of time, such as hourly periods (Zafar and Pota, 2023). Many studies have been done on NR. The main objectives of the NR are (i) reduction of active losses, (ii) reduction of operation costs, and (iii) improvement of reliability. Given that NR is a non-convex problem, in Gallego Pareja et al. (2023), the mixed-integer linear programming has been used to solve the NR. Other methods used include the mixed-integer conic programming in Jabr (2023). Heuristic and metaheuristic techniques have also been widely considered by researchers in solving the NR problem. In Harsh and Das (2023), a complete review of NR methods has been conducted. In dynamic NR, the DSO must choose the best configuration in the shortest time. That is why the time and accuracy of calculations are so important in the dynamic NR. Load and generation uncertainty in dynamic NR has been investigated in many articles. In Zhai et al. (2018) the dynamic NR method is performed to improve the DER hosting capacity by considering the voltage changes in the three-phase network. Risk-based NR is suggested in Larimi et al. (2016), considering load and generation uncertainty in the presence of reward/penalty schemes. In Razavi et al. (2021), the NR has been performed considering the probability of failure in the DERs. The authors have shown that taking the probability of equipment failure into consideration can be very effective in network configuration.

In recent years, the use of the ESSs in the ODN has been considered (Abdeltawab and Mohamed, 2017), which have applications such as resilience (Lei et al., 2019; Mishra et al., 2022), improving the performance of the DERs (Liu et al., 2020), improving the performance of load response programs (Panda et al., 2022), and improving the performance of price market and social welfare (Xiao et al., 2023; Zhao et al., 2023a). For example, in Lu et al. (2021) based on multi-stage robust optimization, the mobile ESSs are proposed to increase the hosting capacity of the DERs in the DN. In Chen et al. (2022b) based on neural networks, the transportation of mobile ESSs is modeled to increase the DN flexibility. In Ghasemi and Moshtagh (2022), Arif et al. (2019), the authors examine the benefits of the mobile ESSs to increase the resilience of the DN during extreme events. It is also suggested in some papers that mobile ESSs have independent owners and the DSO interacts with them for the ODN (Qin et al., 2021). It is proposed in Nizami et al. (2020), Zepter et al. (2019) that consumers can reduce energy purchase costs in the day-ahead and real-time market by using ESS. In Tushar et al. (2020a), Zheng et al. (2022), the effect of shared ESS on the efficiency of P2P trading has been studied. It is proved that the efficiency of P2P trading based on coalition formation (Tushar et al., 2020a) or non-cooperative (Zheng et al., 2022) games is improved by considering the shared ESS due to the increase in prosumers' profits. In Zhong et al. (2020), Hafiz et al. (2019), a combinatorial auction-based shared ESS is proposed to increase social welfare and society's profit, which shows that shared ESS has a significant effect on increasing social welfare and society's profit by reducing the cost of purchasing energy from the wholesale market (see Table 2).

According to Table 1, in the fourth generation of DNs, the role of prosumers will expand significantly, which will lead to changes in the ODNs. P2P trading creates an opportunity for prosumers to exchange energy with each other individually or in groups like a virtual power plant or even in a microgrid without the involvement of the DSO. The development of P2P trading creates some potential risks for DNs, such as reducing network stability, security, and privacy, and suboptimal ODNs. Various issues have been raised in the literature to reduce the potential risks of developing P2P trading (Tushar et al., 2021b; Soto et al., 2021). For example, increasing the DSO's understanding of prosumers' behavior is an important issue in reducing the potential risks of developing P2P trading because the coordination between the decisions of the DSO and prosumers increases when the DSO has a sufficient understanding of the prosumers' behavior. In this regard, increasing the security and privacy of DNs and prosumers is another important issue that is known to deal with the potential risks of developing P2P trading. On the other hand, regulatory policies and control strategies can play a very important role in reducing the potential risks of developing P2P trading. Despite extensive studies in these fields, there are still many challenges in reducing the potential risks caused by the development of P2P trading, which we need to review, analyze, and categorize existing approaches to overcome them. For example, modeling the actual behavior of prosumers, the accuracy and speed of calculations despite the large number of prosumers in the DN, appropriate regulatory policies, and control strategies are among the issues that require more detailed investigation. As a result, the contributions of this article are as follows:

- In addition to categorizing recent papers on mathematical approaches used in P2P trading, a review of the role of players has been made. This issue is important because the role of other traditional players such as the DSOs and retailers in P2P trading will influence the success of the P2P platform.
- A deeper look at game theory from a mathematical point of view is given to help researchers find the limit behavior of prosumers in game environments for P2P trading. This is crucial because, in most of the articles, the prosumers' utility functions in game

Table 2
Overview of recent articles from first to third generation ODNs.

Ref	NR	Mobile ESS	Energy market	Objective function	Generation network	Modeling
Chiou et al. (2005), Ahuja et al. (2007) Malekpour et al. (2012), Razavi et al. (2021)	✓	–	–	active losses, voltage deviation	first	heuristic
Zhan et al. (2020), Lei et al. (2017) Li et al. (2019a), Bai et al. (2018)	✓	–	–	active losses (Zhan et al., 2020), hosting capacity (Lei et al., 2017; Li et al., 2019a; Bai et al., 2018)	second	mathematical programming
Gao et al. (2020)	✓	–	–	active losses, resilience	first	reinforcement learning
Liu et al. (2021)	✓	–	–	quality	first	data-driven
Wu et al. (2022)	✓	–	–	resilience	third	reinforcement learning
Huang et al. (2021), Zheng et al. (2021)	✓	–	–	voltage stability (Huang et al., 2021), cyber attacks (Zheng et al., 2021)	second	reinforcement learning
Nejad and Sun (2021)	✓	–	–	resilience	second	mathematical programming
Kavousi-Fard et al. (2018), Altun et al. (2020)	✓	–	–	active losses, voltage deviation	third (Kavousi-Fard et al., 2018) second (Altun et al., 2020)	mathematical programming
Yao et al. (2019)	✓	✓	–	operation cost	second	mathematical programming
Shen et al. (2018)	✓	–	✓	active losses, voltage deviation	second	mathematical programming
Abdeltawab and Mohamed (2017, 2019) Qin et al. (2021)	–	✓	✓	energy market, voltage deviation	second	mathematical programming (Abdeltawab and Mohamed, 2017, 2019), game theory (Qin et al., 2021)
Lei et al. (2019), Mishra et al. (2022) Home-Ortiz et al. (2022)	✓	✓	–	resilience	second (Lei et al., 2019) third (Mishra et al., 2022; Home-Ortiz et al., 2022)	mathematical programming
Liu et al. (2020)	–	✓	–	operation cost	third	mathematical programming
Prabawa and Choi (2020)	✓	✓	–	resilience	second	multi agent system
Ravi et al. (2022), Golpira et al. (2020)	–	–	✓	operation cost	second	mathematical programming
Du and Li (2019)	–	–	✓	operation cost	second	neural network
Ahmed et al. (2021), Lu et al. (2021) Chen et al. (2022b)	–	✓	–	hosting capacity	second	mathematical programming (Zepter et al., 2019; Lu et al., 2021), reinforcement learning (Chen et al., 2022b)

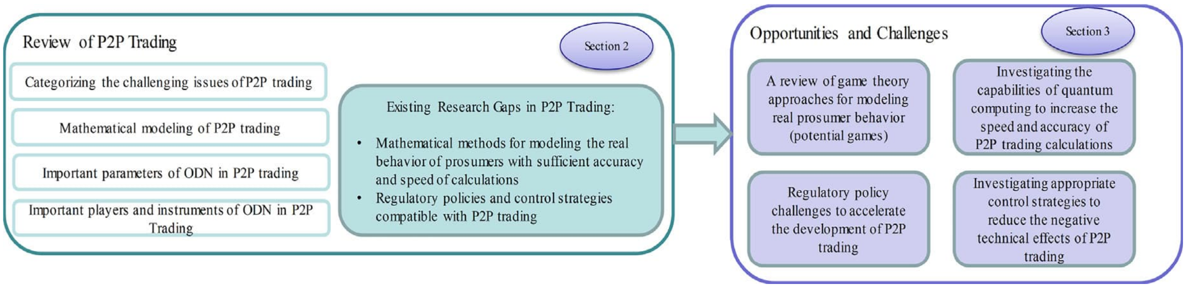

Fig. 1. Structure of the paper.

theory are modeled as a quadratic function, which is different from the practical situations of prosumers' behavior. This disparity results in a difference between the Nash equilibrium calculated in P2P trading modeling based on the quadratic utility function and the limit behavior of dynamics in real cases. Hence, for the first research effort, we explored various mathematical approaches in game theory to determine the limit behavior of prosumers in P2P trading. Additionally, privacy concerns regarding prosumers' information in a game-theoretic environment have been addressed, and various approaches to tackle such challenges have been introduced.

- A deeper look at quantum computing has been developed to increase researchers' understanding of how to harness the potential of quantum computing in P2P trading. This issue is important because recently it has been proven in many papers that quantum computing has great potential for optimization problems related to power systems. On the other hand, as far as we know, quantum approaches in P2P trading have not been considered so far. Hence, for the first research effort, we have investigated the potential of quantum computing in P2P trading.
- In this paper, we provide a review of the regulation in DNs and then examine the challenges and opportunities that regulatory rules present to enhance the interaction between DSOs and prosumers. This issue is important because due to the expansion of the role of prosumers, the interaction between DSOs and prosumers should be expanded to obtain ODNs. In other words, the DSO and prosumers must be aware of each other's concerns and priorities.
- Control strategies to increase coordination between DSOs and prosumers are examined. In fact, the implementation of P2P trading in real DNs will be impossible without proper regulatory rules and control strategies, and it is very important to increase the insight and focus of researchers in this field.

The rest of the paper is organized as follows. In Section 2, we review recent articles by categorizing P2P trading into virtual and physical layers. Then, in Section 3, we categorize future research opportunities and challenges. Finally, Section 4 concludes the paper with a conclusion. The structure of this paper and the relationship of each section is shown in Fig. 1.

2. Review of P2P trading

In recent years, the P2P trading platform has attracted the attention of researchers and many articles have been published about it. One of the important reasons for this attention is that in P2P trading, unlike previous platforms, more attention has been paid to the preferences of prosumers and they can freely seek to increase their profits. In P2P trading, prosumers trade energy in a market structure (virtual layer) and use the DN structure (ODNS) to send and receive energy. As shown in Fig. 2, we categorize the research approaches of interest in the P2P trading articles into four topics and discuss each of them in detail below.

2.1. Virtual layer

The virtual layer essentially provides a secure connection for prosumers to decide on their energy trading parameters. In the articles, different classifications of the virtual layer have been presented. In Tushar et al. (2020b), the virtual layer is classified into four layers, which are information system, market operation, pricing system, and energy management system, or in Haggi and Sun (2021) It is classified into two layers of market structure and pricing. In general, the important challenges in the virtual layer are increasing the motivation of prosumers to participate in P2P trading, pricing, and safe trading.

According to the articles, the virtual layer structure is classified into supervised, unsupervised, and semi-supervised categories. In the supervised structure with the aim of increasing social welfare, there is a coordinator (for example the DSO) in the P2P trading. In this structure, while the ODN is realized, prosumers' privacy is violated, and the coordinator requires a large amount of computation (Lüth et al., 2018; Hou et al., 2019). On the other hand, in the unsupervised structure, the prosumers' privacy is completely preserved and the prosumers follow their preferences regardless of concerns in ODN. As a result, the ODN is not realized in this structure (Nasiri et al., 2023; Khorasany et al., 2019). The semi-supervised structure is a combination of the previous two structures, which enhances communication between coordinators and prosumers so that ODN is realized and prosumers get the most benefit from the P2P trading (Paudel et al., 2018; Moret and Pinson, 2018).

Various mathematical approaches for modeling the structure of the virtual layer have been presented in the articles, which are discussed below, and Table 3 shows a summary of them.

Game theory: In Kalathil et al. (2017), the P2P trading is modeled in a supervised structure, and prosumers' decisions are formulated in a non-convex non-cooperative game, and it is proved that the Nash equilibrium supports social welfare in certain cases. In the same way, Tushar et al. (2020a), Park et al. (2016), prosumers reach the maximum profit in the P2P trading, while the modeling of the virtual layer structure is based on the non-cooperative game. In Chakraborty et al. (2020), the P2P trading based on Nash bargaining is modeled considering the heterogeneous preferences of prosumers, and it is shown that the Nash bargaining model has acceptable results both in increasing individual profit and increasing social welfare. In Chen et al. (2020), Anoh et al. (2019), the Stackelberg game is used as an approach to increase prosumers' profits. In these papers, the prosumers of the seller are modeled as leaders and the prosumers of the buyer as followers in a microgrid. In Cui et al. (2021), game theory approaches in P2P trading have been examined and it has been stated that non-cooperative games do not lead to an increase in social welfare. Therefore, cooperative game-based approaches are more suitable for realizing social welfare than non-cooperative games. However, finding a stable coalition in cooperative models requires the evaluation of all coalitions and their values and is therefore computationally complex in real DNs. Thus, bargaining game models have been proposed to overcome the limitations of cooperative games, which are relatively

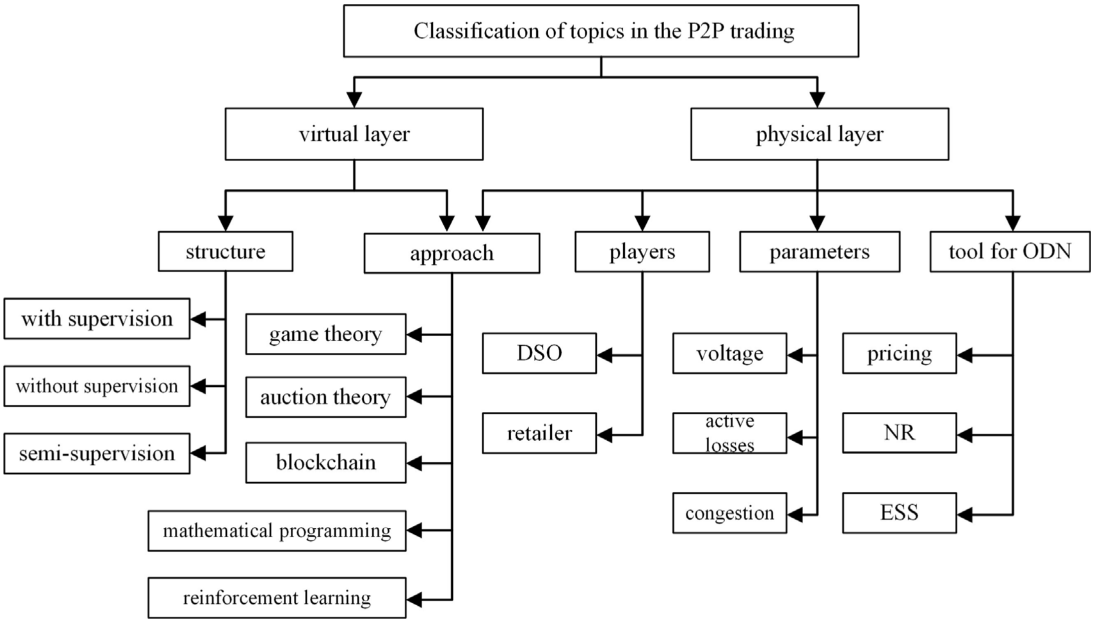

Fig. 2. Classification of topics in the P2P trading.

more practical. However, in bargaining game models, prosumers enjoy the same benefits, which is unfair in reality.

Auction theory: In Zhang et al. (2021), the virtual layer structure is modeled in two day-ahead and real-time markets, while the day-ahead market is based on the cooperative game and the real-time market is based on the auction theory to maximize the benefits of microgrids from energy storage services. In Esmat et al. (2021), El-Baz et al. (2019), the structure of the virtual layer with the presence of electric vehicles is modeled based on the iterative double auction theory, which is calculated with the goal of maximizing social welfare, pricing, and the amount of energy. Also, in Kang et al. (2017), the first attempts to increase the security of transactions and preserve prosumers' privacy using consortium blockchain have been made. In Tsaousoglou et al. (2021), the authors believe that due to the high extent of the P2P trading, the best approach is local analysis. Therefore, they introduce a model based on auction theory, which increases the efficiency of the model with strategic prosumers. In Guerrero et al. (2021), Liu et al. (2019a), an unsupervised structure is proposed that uses auction theory to prevent consumers from deviating from actual demand. Readers interested in comparing auction and bidding methods as well as uniform and discriminatory auctions in P2P trading can refer to Lin et al. (2019).

Mathematical programming: One of the most widely used methods used in articles is the alternating direction method of multipliers (ADMM). For example, in Yang et al. (2020), the P2P trading between several microgrids with a supervised structure is introduced, which is calculated based on the ADMM, the optimal energy sharing between them. In Ullah and Park (2021), fast ADMM is used to speed up the convergence rate, while a distributed pricing strategy for the P2P transactions considering voltage deviation and line congestion management is presented. In Lyu et al. (2021), the P2P trading for smart buildings is introduced by simultaneously considering active prices and losses in an unsupervised structure based on the ADMM dual consensus algorithm, which does not require a coordinator to update the primary and dual variables in the iteration process.

Blockchain: By expanding the application of blockchain from the financial field to the energy field, the concept of *energy blockchain* has been proposed. In fact, blockchain is a distributed data structure that is replicated and shared among members of a network. With blockchain, applications that previously only ran through a trusted intermediary can now run unsupervised (Tushar et al., 2020b). One of the blockchains used in P2P trading is smart contracts. These types of contracts enable automatic control of energy transfers in a repeatable, secure, verifiable, and reliable manner. This trust should be based on things such as privacy protection, the impossibility of denying a transaction after saving it, the low possibility of data falsification, and being flexible against possible attacks (Siano et al., 2019). In this regard, in Thomas et al. (2019), Hasankhani et al. (2021), the conceptualization of smart contracts in P2P trading is discussed. In Li et al. (2019b), it is proposed to use consortium blockchain in the design of the virtual layer of the P2P trading because it has high computational capability. In Liu et al. (2019b), a lightweight blockchain system called Lightchain is proposed, which is efficient in terms of resources and suitable for energy constraints. In Devine and Cuffe (2019), blockchain-based energy value over time is proposed that in equilibrium and with rational prosumers, the pricing mechanism causes generation and consumption to temporarily align.

Reinforcement learning: Due to the extent of the P2P trading and the uncertainties of the DERs, some articles have suggested that instead of using conventional modeling techniques, reinforcement learning-based modeling should be used (Chen, 2022). In Qiu et al. (2021), the pricing mechanism is proposed as a multi-agent problem, which is formulated based on deep reinforcement learning (DRL). In this paper, it is shown that DRL has low computational complexity and preserves prosumers' privacy well. In this regard, it is proposed in Wang et al. (2021), Qiu et al. (2022) that the virtual layer is modeled based on DRL because the privacy of prosumers is well preserved. In Chen et al. (2021), P2P trading modeling in a large DN based on a hybrid multi-agent DRL approach is proposed. This modeling proves that hybrid multi-agent DRL is very suitable for large DNs with high complexity and computational load, and the convergence of modeling can be guaranteed.

2.2. *Important parameters of ODN in P2P trading*

As shown in Fig. 3, various parameters are affected by P2P trading. In other words, one of the issues raised in modeling the virtual layer is a structure considering the parameters of ODNs, which are discussed below.

Voltage deviation: Voltage deviation can be identified as the most important modeling parameter in the virtual layer. In particular, P2P trading can have a two-way effect on voltage deviation if the voltage in some nodes is lower than the standard, the P2P trading can help them

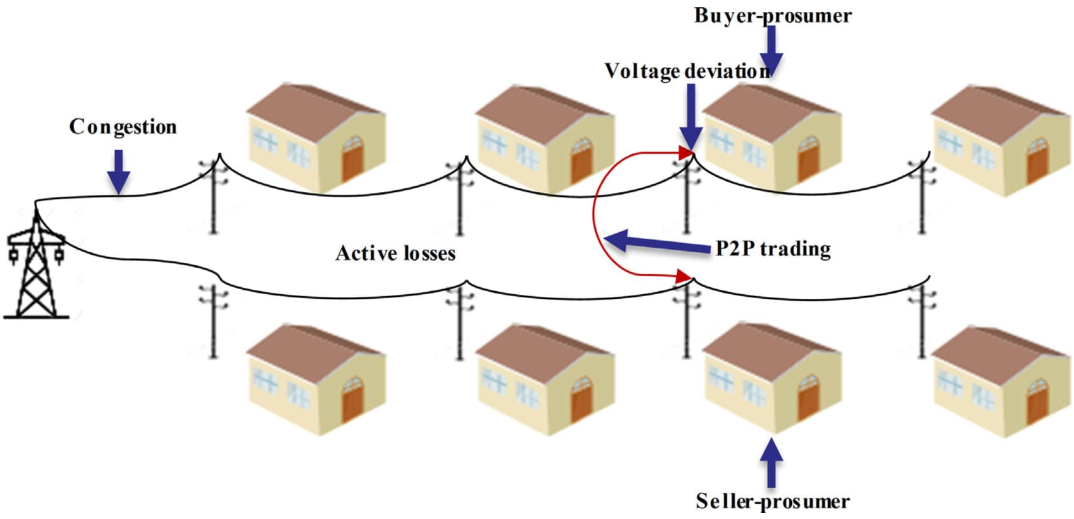

Fig. 3. Various parameters affected by P2P trading.

and bring the voltage to the desired level, but at the same time, if the penetration the P2P trading goes higher and higher, it may cause the voltage to increase from the permissible range (Paudel et al., 2020a; Guerrero et al., 2018). In this regard, in Azim et al. (2021), there is communication between the physical layer and the virtual layer, and based on that, a management plan is proposed in the P2P trading formulation so that none of the prosumers violate the voltage limits. In Hayes et al. (2020), a P2P structure is designed that does not increase the peak demand normally, as a result, the voltage deviation caused by the P2P trading will not happen.

Active losses: The active losses are widely accepted as another important parameter in the physical layer in P2P trading. In Azim et al. (2020), for the first time, a comprehensive study on the reduction of active losses in large DNs with 8500 nodes based on the concept of effective nodes area has been carried out. In Baroche et al. (2019), it is suggested that active losses reduction is guaranteed based on high-cost incentives such as operational, tax, and policy costs of physical layer constraints. In Paudel et al. (2020b) based on the electrical distance in a supervised P2P trading structure, the increase in losses is avoided. In Bai and Crisostomiy (2020), an innovative approach based on conventional path tracking and power tracking for active losses control is proposed. Also in Guerrero et al. (2019), based on sensitivity analysis, active losses in the P2P trading have been investigated. In Haggi and Sun (2021), based on the auction theory together with the average pricing mechanism, the pricing strategy in the P2P trading is controlled in such a way that it leads to the reduction of voltage deviation, active losses, and line congestion. Finally, in Kim and Dvorkin (2019), the structure of the virtual layer has been formulated based on the distribution locational marginal price (DLMP) to maintain the active losses limits.

Other topics: Realization of the virtual layer, in reality, requires sufficient line capacity. It is mentioned in Le Cadre et al. (2020) that the congestion of lines is highly dependent on the price of energy in the virtual layer. In other words, some lines experience high currents and some low currents in P2P trading. In this regard, in Tushar et al. (2019b), based on the Stackelberg game is proposed that P2P trading should be implemented only at peak demand. On the other hand, the imbalance of phases can be very important in the physical layer because it causes an increase in voltage deviation or active losses. In Horta et al. (2018b), a dynamic phase shift model is introduced that can deal with the problems caused by DERs in P2P trading. In this regard, in Horta et al. (2018a), the real-time control model is proposed to balance the phases. Also, another important point in P2P trading can be cyber attacks. Because in P2P trading, the information of many prosumers is related to each other, which greatly increases the possibility of cyber attacks. In Jhala et al. (2019), the effects of cyber attacks on the physical layer have been investigated and it has been shown that if the price and load signals are attacked, they can have very destructive effects.

2.3. Important players and instruments of ODN in P2P trading

As stated in Section 1, P2P trading will significantly change the governance structure in power systems, which will lead to changes in the behavior of traditional players (DSOs, retailers, and aggregators). As a result, as summarized in Table 4, one of the important issues in the implementation of P2P trading is the communication between traditional players and prosumers, which is discussed below.

The DSO is considered one of the important players in DNs that seek to realize ODN. Therefore, communication between DSO and prosumers is very important in P2P trading. In Paudel et al. (2020b), it is proposed that the DSO uses an electrical distance approach to influence prosumers' behavior in such a way that ODN is realized. In this regard, it is suggested in Baroche et al. (2019), Kim and Dvorkin (2019) supervised structure that DSO based on DLMP affects prosumers' decisions. In Zhang et al. (2020), it is proposed that DSO implement the ancillary services market alongside the P2P trading to realize ODN. In this regard, in Morstyn et al. (2019), Sampath et al. (2021), Ullah and Park (2022a), the communication between DSO and virtual layer based on DLMP and ADMM is proposed. In Yan et al. (2020), a bi-level model of the DSO and virtual layer is proposed, in which the upper level of DSO uses NR to realize ODN, and in the lower level, the P2P trading between several microgrids is modeled based on the Stackelberg game. In this regard, in Zou et al. (2022), the NR with the aim of reducing active losses by the DSO with the P2P trading mechanism is proposed. In Ji et al. (2021), Zhao et al. (2023b), it is proposed that DSO based on NR and smart contracts realize ODN. In Botelho et al. (2022), the uncertainty of DERs in the P2P trading is considered and a Monte Carlo simulation-based ODN is proposed. In Nguyen et al. (2018), the profit of prosumers is modeled by considering the ESS, the cost of using the DN, and retail tariffs, and it is proved that the role of ESSs in increasing the profit of prosumers in the P2P trading is significant. In Zepter et al. (2019), the role of P2P trading in day-ahead and real-time markets is explored, and it is proposed that DSO use an ESS for ODN.

The integration of P2P trading and LMs has been discussed in a few limited works. A framework for simultaneous P2P trading and LMs is presented in Park et al. (2021) where prosumers are grouped as communities and each community is required to maintain flexibility during the P2P trading to ensure an ODN. In Orlandini et al. (2019)

Table 3
A summary of topics related to the virtual layer in P2P trading.

Ref	Mathematical approach	Structure	Parameters	Ref	Mathematical approach	Structure	Parameters
Tushar et al. (2020a)	game theory (cooperative)	semi-supervision	–	Tushar et al. (2019b)	game theory (Stackelberg)	with supervision	congestion
Guerrero et al. (2019)	game theory (Stackelberg) and blockchain	with supervision	congestion	Kim and Dvorkin (2019)	OPF	semi-supervision	active losses
Anoh et al. (2019), Jiang et al. (2020)	game theory (Stackelberg)	without supervision	–	Horta et al. (2018a)	game theory and control theory	semi-supervision	voltage deviation and congestion
Liu et al. (2019b)	game theory (cooperative)	without supervision	–	Haggi and Sun (2021)	ADMM	with supervision	active losses and congestion
Kalathil et al. (2017)	game theory (non-cooperative)	semi-supervision	–	Guerrero et al. (2019)	game theory (Stackelberg)	with supervision	congestion
Park et al. (2016)	game theory (non-cooperative)	with supervision	–	Azim et al. (2020), Baroche et al. (2019)	OPF	with supervision	active losses
(Tushar et al., 2020a), Cui et al. (2021)	game theory (bargaining)	without supervision	–	Guerrero et al. (2018)	OPF and blockchain	without supervision	voltage deviation
Zhang et al. (2021)	game theory (non-cooperative)	semi-supervision	–	Azim et al. (2021)	game theory (cooperative)	without supervision	voltage deviation
Kang et al. (2017)	auction theory and consortium blockchain	without supervision	–	Qiu et al. (2021)	reinforcement learning	without supervision	–
Esmat et al. (2021)	auction theory and smart contract	semi-supervision	–	Liu et al. (2019b)	game theory (cooperative)	without supervision	voltage deviation
Guerrero et al. (2021)	auction theory	without supervision	voltage deviation	Thomas et al. (2019)	smart contract	without supervision	–
Liu et al. (2019a)	auction theory	without supervision	voltage deviation	Siano et al. (2019)	lightchain	without supervision	–
El-Baz et al. (2019)	auction theory	without supervision	–	Lyu et al. (2021)	ADMM	without supervision	active losses
Ullah and Park (2021)	ADMM	without supervision	voltage deviation	Yang et al. (2020)	ADMM	without supervision	–
Horta et al. (2018b)	mathematical programming	with supervision	congestion	Jhala et al. (2019)	mathematical programming	with supervision	cyber attacks
Chen (2022)	reinforcement learning	with supervision	–	Qiu et al. (2022)	reinforcement learning	with supervision	–

Table 4
A summary of the role of the traditional player in P2P trading.

Ref	Player	Tool for ODN	Mathematical approach
Paudel et al. (2020b), Baroche et al. (2019)	DSO	electrical distance	mathematical programming
Hanif et al. (2018)	DSO	DLMP and LM	mathematical programming
Morstyn et al. (2019), Sampath et al. (2021), Ullah and Park (2022a), Kim and Dvorkin (2019), Zhang et al. (2020)	DSO	DLMP	mathematical programming
Yan et al. (2020)	DSO	NR and LM	game theory
Zou et al. (2022), Zhao et al. (2023b)	DSO	NR	game theory
Ji et al. (2021)	DSO	NR	blockchain
Botelho et al. (2022)	DSO	–	Monte Carlo simulation
Park et al. (2021)	DSO	DLMP and LM	game theory
Orlandini et al. (2019)	DSO	DLMP and LM	mathematical programming
Khorasany et al. (2022), Zhou et al. (2022)	DSO	DLMP and LM	auction theory
Tushar et al. (2021a)	DSO and retailer	LM	game theory
Huang et al. (2022)	DSO and retailer	DLMP and LM	mathematical programming
Mehdinejad et al. (2022), Rashidizadeh-Kermani et al. (2021)	retailer	–	mathematical programming
Faia et al. (2021), Nguyen et al. (2018)	DSO and retailer	ESS	mathematical programming
Zepter et al. (2019)	DSO	ESS	mathematical programming

it is proposed that the DSO modify the results of the P2P trading by using the flexibility of prosumers for ODN. In Khorasany et al. (2022), a community-based LM is proposed that allows prosumers to participate with DSOs for ODN in addition to the P2P trading. Similarly, in Zhou et al. (2022), based on a dual auction mechanism, the P2P trading and the ancillary service market are proposed.

Considering the characteristics of the P2P trading and retail-based electricity markets, a model of retail-based P2P trading is proposed in Tushar et al. (2021a) where prosumers can trade their energy both in the P2P trading and with retailers. Also, A two-stage retail market is proposed based on DLMP and ADMM in Huang et al. (2022), which models energy trading between DSOs and microgrids with P2P trading. In Mehdinejad et al. (2022), based on the primal–dual sub-gradient algorithm, it is proposed that retailers participate in the P2P trading as intermediary players and trade prosumers' energy between each other or with the upstream network. In this regard, in Faia et al. (2021), the impact of ESSs on retail and P2P trading is modeled based on mixed integer linear programming. Finally, it is suggested in Rashidizadeh-Kermani et al. (2021) that retailers use wind farms to increase their profit from the P2P trading mechanism.

2.4. Existing research gaps in P2P trading

In this section, we investigated the mechanism of P2P trading in DNs and considered various mathematical approaches both in the virtual layer and in the physical layer. Our investigations show that due to the main concept of P2P trading that supports the freedom of prosumers to make decisions, many papers have proposed P2P trading modeling in an unsupervised structure based on game theory. By taking a closer investigation at the approaches used in game theory in modeling P2P trading, we have come to the conclusion that these modeling are in their early stages and many issues have not yet been addressed. Also, preserving the privacy of prosumers, reducing the calculation load in large DNs with a large number of prosumers, and using different DN equipment such as NR and ESS to increase coordination, are other challenges of P2P trading modeling. It seems that in the coming years, researchers will focus more on finding suitable solutions for P2P trading modeling with these issues. In other words, there are potential mathematical challenges such as lack of convergence in integrating these issues with P2P trading modeling that researchers need to address.

In the continuation of this section, we discussed the role of various players, including DSOs and retailers in P2P trading. Our investigations show that the articles mainly focus on the virtual layer and the market mechanism, and little attention is paid to the physical layer and technical parameters of the network (ODNs). It can also be concluded that the impact and efficiency of various players in P2P trading and their possible behavior change were not considered by the researchers. In other words, the role of the DSO and its performance in expanding P2P trading has received less attention. Our investigations show that the DSO's lack of attention to the concerns of each prosumer will lead to the failure of the P2P platform.

3. Opportunities and challenges

According to the reviews in the previous section, there are still various issues with the implementation of ODN-compliant P2P trading that have received little attention. For example, appropriate mathematical approaches to match real-world conditions and appropriate policies for coordination between prosumers and DSOs are among the topics that have potential for further investigation. Therefore, in this section, as shown in Fig. 4, the opportunities and challenges of implementing P2P trading have been investigated.

3.1. Mathematical modeling

A significant focus has been made in the literature with the aim of developing mathematical approaches for modeling P2P trading, especially the virtual layer. More precisely, issues such as determining the market clearing price, prosumers' behavior, privacy, etc. are among the challenges related to P2P trading modeling, which various mathematical approaches, as discussed in detail in Section 2.1, have been proposed in the literature. However, it seems that the proposed approaches are still not perfect for modeling P2P trading in real-world conditions, especially for issues related to ODNs. Therefore, in this subsection, we have examined two important challenges, which are: (1) modeling the limit behavior of prosumers, and (2) high computational accuracy and speed. In fact, these challenges are known as future research opportunities related to ODN, because DSO must understand the concerns and priorities of prosumers well (related to the limit behavior of prosumers) and make optimal decisions with high computational accuracy and speed in order to achieve optimal ODN.

3.1.1. Game theory

Game-theoretic approaches provide an excellent foundation for analyzing the strategic behavior of a network of agents. As stated in Section 2, many game-theoretic approaches for P2P trading have been proposed, indicating the crucial role of game theory analysis in P2P trading. Particularly, game theory has been employed to optimize prices in smart grids (Tushar et al., 2012), manage energy for P2P trading (Tushar et al., 2018), demonstrate stability among different

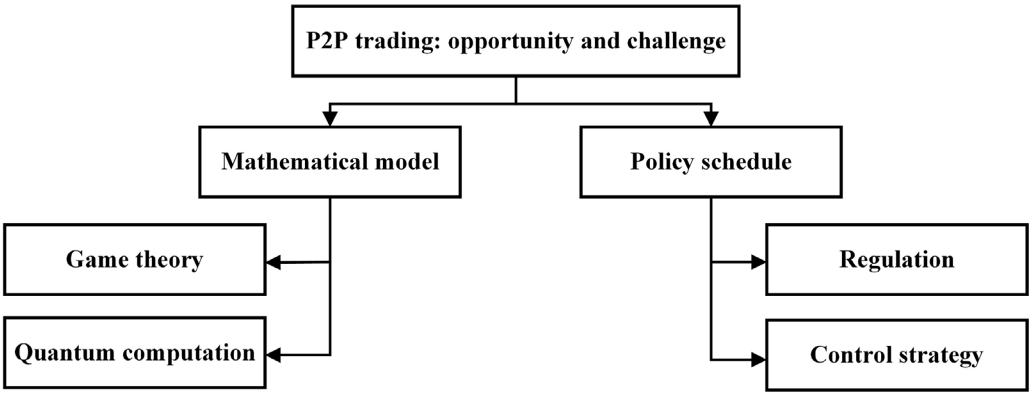

Fig. 4. Opportunities and challenges in P2P trading.

prosumers in P2P trading (Tushar et al., 2019a), and achieve optimality in energy trading (Tushar et al., 2014).

More precisely, traditionally, the behavior of players in power systems is modeled based on a quadratic function. This is because quadratic functions are convex, and from a mathematical standpoint, we can calculate the optimal point well. Additionally, from an economic perspective, these functions effectively represent the marginal cost of players. Despite the undeniable advantages of quadratic functions in modeling players' behavior, as discussed in Moncada et al. (2021), Wolske et al. (2020), using quadratic functions for players' behavior modeling is not accurate. The closer we get to the actual behavior of players in the real world, the further away we move from quadratic functions. The significance of this issue increases significantly in P2P trading. As discussed in Poudineh et al. (2015), due to the large number of prosumers, DSO must enhance its understanding of the prosumers' concerns and preferences. Increasing the understanding of DSO requires appropriate modeling of P2P trading based on game theory, taking into account the actual prosumers' behavior. Consequently, a crucial research challenge arises in this field because DSO must determine the final outcome or limit behavior of P2P trading with exact utility functions of prosumers. In other words, computing the outcome of P2P trading with general utility functions is a mathematical challenge since the limit behavior of players in general games is difficult to track. Additionally, computing Nash equilibrium as an indicator for the outcome of the game may not be accurate, as the dynamics of players' actions may not converge to Nash equilibrium in general games. To address this challenge, we focus on the mathematical aspect of game theory, attempting to determine the limit behavior of prosumers in general games. More precisely, we study the behavior of prosumers in general games without a simplified predefined structure. Additionally, we address the privacy of prosumers in the game environment, which is essential for our application in P2P trading.

Limit behavior: The desirability of an optimal ODN is often addressed by the limited behavior of the actions of agents which is either the equilibrium at which their actions converge or the region where their actions eventually lie in. Even with the same utility function, depending on the update rule agents respond to others' actions, and the limited behavior of agents may be quite different. Among different game dynamics, fictitious play, best response dynamics, and better response dynamics are the most famous of them.

It is well known that potential games, where a single potential function can express the agents' incentive to change their actions (Monderer and Shapley, 1996), have special characteristics that help us track the dynamics in them much easier than general games, leading to a number of results for various types of dynamics in potential games. For instance, it is proved that best response dynamics and fictitious play converge to Nash equilibrium in potential games. But in many practical applications, game models are not potential games, which is why an appropriate analysis should be utilized for analyzing the limit behavior of agents in general games.

Several approaches are trying to determine such limit behavior in general games (Hahn and Moon, 2010; Balcan and Braverman, 2017). However, their approaches are not often generalized to all sets of games or all sets of update rules. To the best of our knowledge, there are two approaches that are applicable generally for the limit behavior of agents in general games. The first one is near potential analysis (Candogan et al., 2013) and the second one is near contraction analysis (Arefizadeh et al., 2023), which are discussed in subsequent paragraphs.

As indicated before, in many cases dynamics in potential games converge to Nash equilibrium. The paper in Candogan et al. (2013) has addressed if similar behavior is to be expected for the games that are not potential but close to potential games. To express the results, first, the closeness of one game to the other should be defined mathematically.

Definition 1 (*Maximum Pairwise Difference-MPD*)**.** Let G and $\hat{G}$ be two games with the same set of players and action sets. For an action set $a=(a_i,a_{-i})$, considering $d^G_{(a_i',a)} := u_i(a_i',a_{-i})-u_i(a_i,a_{-i})$ be the difference in player i's utility when the action is changed from a_i to a_i' (similarly $d^{\hat{G}}_{(a_i',a)}$ is defined). Then, the maximum pairwise difference between the two games G and $\hat{G}$ is defined as

$$d(G,\hat{G}) := \max_{i,a_i',a} |d^G_{(a_i',a)} - d^{\hat{G}}_{(a_i',a)}|. \tag{1}$$

This definition actually introduces a new metric that can determine how close one game is to another. Near potential game is a game that has a small MPD to a potential game. It is obvious that all general game has an MPD with a given potential game that has the same set of players and actions, however, it is important to find a potential game with a minimum MPD level, since, as previously mentioned, it can be expected that the original game will behave similarly to this potential game. In other words, in these two games, the similarity of dynamics should be directly related to their distance from each other, so finding the potential game with the least distance from the original game would be desirable. To illustrate the results, first, we should define the concept of epsilon Nash equilibrium.

Definition 2 (*ϵ-Nash Equilibrium*)**.** For an arbitrary game, an action profile $a=(a_1,\dots,a_N)$ is called an ϵ-Nash equilibrium ($\epsilon \geq 0$) if

$$u_i(a_i';a_{-i}) - u_i(a_i;a_{-i}) \leq \epsilon \tag{2}$$

for every a' and any player i. $\mathcal{X}_\epsilon$ is the mathematical representation of the set of ϵ-Nash equilibrium. It is worth mentioning that Nash equilibrium is a special type of ϵ-Nash equilibrium when $\epsilon = 0$.

One of the most important results of the paper (Candogan et al., 2013) is that it proves that best response dynamics in a near potential game will be trapped in $\mathcal{X}_{\delta|\mathcal{A}|}$, an ϵ-Nash equilibrium where $\epsilon = \delta|\mathcal{A}|$. Consequently, if we want to characterize the limit behavior of agents following best response dynamics in a game environment, we have to find its near potential game resulting in determining an ϵ-Nash equilibrium as the region where the dynamics eventually will be trapped.

The near potential game analysis gave rise to another approach to address the dynamics in general games. This novel method, known as near contraction analysis (Arefizadeh et al., 2023), seeks to analyze the overall dynamics of games from a different perspective. In the previous analysis, the main insight indicated that dynamics in games that are close to a potential game should exhibit similar behavior. The near contraction analysis indicates that the dynamics in games that are near to a contractive mapping, which converges to a single point, must be close to the converging point in contractive mapping. This approach offers a crucial tool for addressing various types of dynamics in games, making it more applicable for the analysis of general dynamics compared to the previous approach, which only allowed for the analysis of specific types of dynamics. In the end, both approaches may be utilized to achieve even better results. To discuss the near contractive analysis, first, we should define contractive mapping.

Definition 3 (*Contractive Mapping*)**.** A map $C : \mathbb{R}^N \to \mathbb{R}^N$ is called contractive if

$$\|C(x) - C(y)\| \leq L_C\|x - y\|, \tag{3}$$

for some $L_C < 1$ and all $x, y \in \mathbb{R}^N$. Every contractive map C has a fixed point x^*, such that $C(x^*) = x^*$.

The fundamental result presented by Arefizadeh et al. (2023) states that considering $Z : D \to D \subseteq \mathbb{R}^N$ as mappings representing game dynamics, where D is the whole domain of agents actions, and considering map Z, eventually got trapped in a bounded domain $D' \subset D$, then there exists a contractive mapping $C : D \to D$ with Lipschitz constant L_C, such that for some $\delta_2 > 0$, $\|Z(x) - C(x)\| \leq \delta_2, \forall x \in D'$. Moreover, as $n \to \infty$, the sequences $Z^n(x^0)$ converges to $N_{\delta_2/(1-L_C)}(x^*)$, which is the area in open ball of radius $\delta_2/(1 - L_C)$ around x^* in euclidean distance and x^* is the fixed point of map C. As a result, using this result, we can obtain tighter characteristics of limited behavior of dynamics in games. In Arefizadeh et al. (2023), it is proved that for best response dynamics in repeated games, such a bounded set always exists. Nevertheless, in every dynamic in every game, as long as we have bounded action space, this result is applicable.

In the near potential analysis, we are required to find the potential game that is close to the original game with respect to its MPD. Although we can use any potential game and find its corresponding MPD to characterize the original game's asymptotic dynamics with respect to it, since MPD may be quite big, the derived asymptotic region may not be quite useful. The near contraction analysis has a similar issue, meaning that we can characterize the game dynamics by any contractive map, but the final asymptotic region may not be useful. As a result in both cases, we are interested in finding a potential game or contractive map close enough to the original game or original dynamics in the game to give us suitable results. Finding the nearest potential game to any given game is formulated in Candogan et al. (2013) as a convex optimization problem. However, the optimization problem is not solvable generally since we have to search in the space of functions. However, if we restrict ourselves to a specific class of potential games, we can find the closest potential game to any given game in that class. The same argument is true for the near contraction analysis approach where we can find the best contractive map with a predetermined structure by solving an optimization problem.

While the mentioned procedure to use these analyses is useful for finding the asymptotic behavior of agents, we can use these analyses in a more straightforward way. In many situations, the strategic environment can be modeled as a potential game or the game dynamics can be modeled as a contraction map but in order to be more precise, a perturbation term is included in such modeling. This assumption eliminates the procedure needed to determine the closest potential game for near potential analysis or to determine the near contractive map for near contraction analysis. This perspective is especially addressed in Arefizadeh et al. (2023) where a perturbation of the Cournot game is addressed and has been shown that the asymptotic behavior of the perturbation lies in a region near to contraction point of Cournot game dynamics. It is worth mentioning that the Cournot game is widely used as a model in many situations and has many applications in smart grids (Zhang et al., 2019), indicating its important role.

Privacy: One of the challenges that will become more important in the implementation of P2P trading in the coming years is the protection of prosumers' privacy. In fact, privacy protection is recognized as one of the priorities of prosumers and one of the challenges of DSO, because the disclosure of prosumers' information increases the risk of cyber-attacks and inappropriate ODN. In some papers, privacy enhancement in P2P trading has been investigated, for example in Umer et al. (2021) distributed ADMM-based P2P trading is proposed, which does not require a third party to clear the market. In this regard, prosumers' data is encrypted in Zhang et al. (2023) based on the blockchain, which leads to the preservation of privacy. In Mu et al. (2022), an entangled circuit based on multi-party computation is proposed to compare prosumers' prices without disclosure. In Xia et al. (2022) privacy protection based on the combination of Benders decomposition and the Stackelberg game is proposed which has higher robustness compared to the ADMM approach.

Privacy concerns have been addressed in the game-theoretic perspective. Since information disclosure of one entity may be desirable for some entities while harmful for others, there is a conflict of interest, creating a strategic setting that can be perfectly analyzed using game theory (Shah et al., 2019). In Baby et al. (2015), a new technique has been developed using game theory to avoid the collision of two players from exposing the private information of other players while Nash equilibrium can be achieved. In Kumari and Chakravarthy (2016), a new model for privacy preservation has been proposed using cooperative game theory, where each player tries to maintain her privacy results in keeping other players privacy. In Arefizadeh et al. (2022) a novel technique in a game setting has been proposed where welfare is considered as the objective function and privacy concerns are considered as the limitation, resulting in modeling an optimization problem where the objective function is the welfare and the level of required privacy is modeled as a penalty, creating an excellent framework to address the problem of trade-off for preserving privacy and achieving the network optimality.

3.1.2. *Quantum computation*

One of the critical challenges of ODN in the fourth generation of DNs is the computational complexity caused by the development of technologies. As stated in Section 1, in fact, ODN is an optimization problem with binary and continuous variables that DSO must calculate in a short time and with appropriate accuracy. With the expansion of prosumers in distribution networks, solving the ODN problem becomes more complex, because the technologies used in P2P trading add complex variables with high uncertainty to the ODN problem, which is difficult to solve by existing classical methods (Eskandarpour et al., 2020). In other words, the use of existing classical methods in power grid optimization problems has become challenging due to the spread of different technologies and changes in the behavior of end consumers (Ajagekar and You, 2019). As a result, the attention of researchers has recently been drawn to mathematical approaches based on quantum technology to solve these problems.

Quantum-based optimization in power system topics: In Morstyn (2022), an annealing-based quantum method is proposed to calculate the optimal power flow, which is more suitable than classical methods in industrial applications. In this regard, a conceptual model of quantum-based power flow is proposed in Feng et al. (2021), which is based on Hermitian and constant Jacobian matrices. One of the important challenges in using quantum-based approaches in real conditions is noise in quantum computers. Therefore, in Sævarsson et al. (2022) using 5 quantum computers, the results of quantum-based power flow have been investigated, which shows that there are still many challenges for using quantum-based power flow in real conditions. Also, another challenge of power flow is related to calculations in DC networks, which is proposed in Gao et al. (2023) based on the quantum HHL algorithm, DC power flow.

The problem of unit commitment is another topic that has received attention based on quantum approaches in recent years. In Koretsky et al. (2021), the quantum approximate optimization algorithm (QAOA) is proposed to solve the unit commitment problem. In this regard, in Paterakis (2023), the unit commitment problem is proposed by combining the classic Benders decomposition approach and rewriting quadratic unconstrained binary optimization (QUBO) based on Ising models. In the following, the transfer of QAOA and QUBO to Ising models is discussed from a mathematical point of view.

Combined quantum and classical optimization: The first step for optimization by combining quantum and classical methods is to create suitable hardware. Therefore, Ising machines are proposed, which transform the classical optimization problem into Ising machines (Golestan et al., 2023). In Gambella and Simonetto (2020) the convergence of the ADMM approach with Ising machines is guaranteed. It is also modeled in Zhao et al. (2022), Gao et al. (2022), Benders decomposition approaches with Ising machines. This issue can be very important for solving ODN by DSO because the ADMM approach is used in some articles such as (Sampath et al., 2021; Ullah and Park, 2022a), and combining this approach with Ising machines can improve convergence and calculation speed. In fact, the main problem in the combination of quantum and classical methods is the mapping of functions from the classical structure to the Hamiltonian. In other words, to combine classical and quantum methods, a Hamiltonian representing Boolean functions is needed, i.e. $H_f|x\rangle = f(x)|x\rangle$. where H_f is the Hamiltonian function $f : \{0,1\}^n \rightarrow \{0,1\}$, and $|x\rangle = \{x_1, \ldots, x_n\}^{\intercal}$.

Theorem 1. *We have a unique Hamiltonian for each function f (Hadfield, 2021):*

$$H_f = \sum_{S\subset[n]} \frac{1}{2^n}\left(\sum_{x\in\{0,1\}^n} f(x)(-1)^{\sum_{j\in S} x_j}\right)\prod_{j\in S}\left(I\otimes\cdots Z_j\otimes\cdots I\right), \qquad (4)$$

where Z_j is a matrix with eigenvalues 1 and −1.

Based on Theorem 1 we can calculate the objective functions in quantum annealing. Note that in general, this is the first step to combine classical and quantum optimization. In other words, the problem is expressed as an Ising model, and then a partial embedding must be created with the compatibility of the physical connection between the qubits.

3.2. Policy schedule

The fourth generation of DNs has led to fundamental changes in the communication between DSOs and prosumers, which requires changes in regulatory rules and control strategies. Because on the one hand, prosumers want to increase their profit and on the other hand, DSO needs to achieve optimal ODN. As a result, there is a need for deep communication between DSO and prosumers, and regulatory rules and control strategies play a prominent role in strengthening this communication (Connor et al., 2014). Thus, in this sub-section, we describe the opportunities and challenges related to regulation rules and control strategies in DNs with P2P trading.

3.2.1. Regulation rules

It seems that the first step to developing the communication between DSOs and prosumers is to expand and/or change the authority of DSOs. In Reeve et al. (2022) the authors claim that the role of the DSO should be defined as the role of the independent system operator and/or transmission system operator. In this regard, it is proposed in Pereira et al. (2018) that DSOs should coordinate ODNS with the facilitation of P2P trading, increasing the social welfare and privacy of prosumers. However, due to the high number of prosumers, DSO must know **what** tools, **how** and **where** can be effective to increase communication with P2P trading. On the other hand, the regulatory rules from the first generation to the third generation of DNs include cost-based and incentive-based approaches and according to the changes in the fourth generation of DNs, these rules should also be changed (Gwerder et al., 2019).

In Laaksonen et al. (2021), the authors state that the acceleration of achieving the fourth generation of DNs is dependent on regulations such as tariffs and taxes. In this regard, one of the challenges of expanding the fourth generation of DNs in Brazil is the lack of appropriate regulatory rules (Dranka and Ferreira, 2020). Accordingly, in Azim et al. (2020), Ullah and Park (2022a), P2P trading is proposed based on regulatory rules based on fixed or dynamic tariffs. On the other hand, in these articles, the long-term impact of these regulatory rules on the performance of P2P trading is not considered. In other words, the risk of reducing coordination between DSOs and prosumers should be taken into account in regulatory rules based on tariffs and taxes. This means that compatibility between regulatory rules and the concerns of DSOs and prosumers leads to the acceleration of the expansion of the fourth generation of DNs. For example, in Connor et al. (2014) the authors state that social acceptance has been slow due to the incompatibility of regulatory rules with the fourth generation of DNs in the United Kingdom. On the other hand, due to the nature of P2P trading, prosumers' behavior is associated with many uncertainties and the regulatory laws must also be compatible with these uncertainties. In Aghaei et al. (2013), the authors deal with changing the behavior of prosumers with ESS and state that one of the important challenges in adapting regulatory rules to prosumers' priorities is to consider their behavioral uncertainty. In this regard, in Yang et al. (2019), the role of regulatory rules in adapting the uncertainties of electric vehicles to DSO has been investigated and it has been shown that the more consistent the regulatory rules are, the more EVs are expanded in DNs. It is also stated in Giest (2020) that due to the behavioral uncertainty and diversity of prosumers' equipment, regulatory rules should be compatible with different equipment in DNs and not hinder their proper operation.

In Pereira et al. (2020), with the aim of improving the ODNs in the fourth generation of DNs, regulatory rules based on total expenditures are proposed, which are a combination of capital expenditures and operational expenditures. In Bergaentzlé et al. (2021), it is proposed that the regulatory rules be based on behavioral and social sciences because the motivation of prosumers an important role in the expansion of the fourth generation of DNs. In this regard, it has been emphasized in Rohde and Hielscher (2021) that the implementation of regulatory rules should not require extensive changes in prosumers' behavior.

One of the regulatory rules for using demand response and DG in the third generation of DNs is incentive-based programs. In other words, based on these regulatory rules, according to the time of energy consumption, DSO is allowed to offer different incentives to end consumers (Ellman and Xiao, 2020). In this regard, in Sheha et al. (2021) based on the Stackelberg game, and in Lu and Hong (2019) based on reinforcement learning and deep neural network, DSO incentives are modeled. Finally, in Schmitt et al. (2022), it is proposed to expand regulatory rules based on local ancillary services to use the incentives approach in the fourth generation of DNs.

3.2.2. Control strategies

The main idea in P2P trading is to increase the number of prosumers, which achieves this goal by increasing their motivation and independence. The expansion and increase of prosumers mean the increase of DERs, especially photovoltaic with electronic power converters in DNs. One of the ODNs' challenges in the use of DERs is the control systems of their power electronic converters, which becomes more challenging with the development of P2P trading. Considering that in the literature related to P2P trading, prosumer control systems strategies and their combination with P2P trading have been less discussed, hence in this paper, we examine the challenges of prosumer control systems strategies for DERs as a research opportunity.

In Hossain et al. (2017) and Andishgar et al. (2017), the structure of DER controllers is discussed and various methods such as resonant and repetitive controllers are investigated. In general, the DERs control systems strategies with the performance of microgrids are discussed in the literature. On the other hand, P2P trading has also been considered in the framework of microgrids (Wei et al., 2021; Nezamabadi and Vahidinasab, 2020), hence the integration of prosumer control systems strategies in microgrids is very important to implement P2P trading. A control strategy that has been proposed in most papers for the performance of microgrids is hierarchical control (Olivares et al., 2014; Lu et al., 2013). In hierarchical control, the primary level is related to local control, which is usually based on droop control and its purpose is to control local frequency and voltage (Zhang et al., 2018), the secondary level is to control the frequency and internal voltage of the microgrid (Simpson-Porco et al., 2015) and the tertiary level is related to The control is outside the microgrid (Yamashita et al., 2020; Meng et al., 2016). In the literature, control strategies are usually related to AC microgrids, but due to the growth of DC loads, the attention to control DC microgrids has also expanded (Dragičević et al., 2015). Another issue that has been considered in the prosumers' control systems strategies is the structure of the control system. In Cintuglu et al. (2016) centralized control structure is proposed. In this structure, a central controller manages all the primary to tertiary levels of the control system, the most important challenge of which is the volume of calculations. In Weitenberg et al. (2018) a decentralized control structure is proposed. In this structure, the most important challenge is to improve the performance of the secondary and tertiary control levels, because due to the lack of a communication channel between the control systems, their performance faces errors. In Saleh et al. (2019) distributed control structure is proposed. This structure has received the attention of many articles such as (Sahoo et al., 2019), which is considered the best control structure.

4. Conclusion

This paper provided an in-depth review of the operation of distribution networks (ODNs) in the era of peer-to-peer (P2P) trading. First, distribution networks were classified into different generations, and the characteristics and influencing parameters such as (1) network reconfiguration, (2) mobile energy storage systems, and (3) energy market were discussed in the ODN of each generation. Then, by categorizing the ODN approaches in each generation and their outstanding changes, we stated that in the era of P2P trading, ODNs would face many challenges. Furthermore, considering the importance of understanding the characteristics of P2P trading, an in-depth review of recent literature approaches in P2P trading is provided. In previous review papers, attention has been a good paid to investigating the efficiency of P2P trading, therefore for the first research effort, we have addressed the most common P2P trading challenges that have a direct impact on ODN approaches. In other words, there would be still various issues with the implementation of ODN-compliant P2P trading that have received little attention. For example, appropriate mathematical approaches to match real-world conditions and appropriate policies for coordination between P2P trading and DSOs would be among the topics that could have potential for further investigation. Briefly, in our investigations, we found that prosumers' utility functions in P2P trading are mostly modeled using quadratic functions. However, based on our current understanding, this modeling may not accurately represent reality, as prosumers likely possess non-quadratic utility functions. Consequently, this leads to distinct limit behaviors that deviate from the predictions of Nash equilibrium for quadratic utility functions. As a result, we reviewed the literature to find appropriate mathematical approaches to deal with this challenge and we have shown that the existing literature, especially in game theory, has proposed suitable acceptable approaches to deal with this challenge. On the other hand, another challenge is related to the speed and load of calculations in large DNs with a large number of prosumers. Our investigations show that one of the appropriate methods to deal with this challenge is the use of quantum computation because this method has sufficient accuracy and computational speed for large DNs with a large number of prosumers. Ultimately, policies for coordination between prosumers and DSO have been discussed. Our investigations show that with the expansion of P2P trading, regulatory and control approaches in DNs will undergo fundamental changes. The main reason for this is that the DSO has to firstly have a sufficient understanding of the concerns and priorities of the prosumers, and secondly, all the decisions of the DSO have to be adopted based on increasing coordination with the prosumers. By carefully examining the policies available in the literature, we found that little attention has been paid to these issues. As a result, in the coming years, researchers should provide appropriate guidelines for updating regulatory and control schemes in DNs in the era of P2P trading.

Aside from the issues raised in this paper, since the concept of P2P trading in DNs is in its early years, there are still potential risks in its development, which are very important to investigate as future research directions.

Firstly, the uncertainties caused by the production and consumption of prosumers, the Stability of ODNs faces a serious challenge. Therefore, it seems that despite the many studies about the stability of ODNs, the investigation and development of sensors, automation, and real-time monitoring is one of the important issues in overcoming the instability of DNs caused by the development of P2P trading.

Secondly, the structure of DNs is not suitable for the equitable development of P2P trade. For example, if a prosumer is at the end of a distribution feeder, it will have fewer advantages and freedom than another prosumer who is at the beginning of the distribution feeder. This lack of equitable distribution of the opportunity to participate in P2P trading causes a part of the DNs to be very engaged in P2P trading and another part is not involved. As a result, one of the important factors in creating a potential risk for the development of P2P trading is the inequitable structure of DNs. In other words, this makes the ODNs a challenge because there will not be homogeneous planning for the ODNs. Addressing this issue seems to require consideration of incentive and subsidy programs so that all final consumers in DNs have an equitable opportunity to become prosumers.

CRediT authorship contribution statement

Seyed-Mohammad Razavi: Writing – original draft, Formal analysis, Data curation, Conceptualization. **Mahmoud-Reza Haghifam:** Writing – review & editing, Supervision, Investigation, Formal analysis. **Sadegh Arefizadeh:** Writing – review & editing, Validation, Methodology, Investigation. **S.M.M. Larimi:** Writing – review & editing, Visualization, Formal analysis. **Miadreza Shafie-khah:** Validation, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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