JOURNAL OF SOUTHERN COMMUNICATION ENGINEERING
ISLAMIC AZAD UNIVERSITY BUSHEHR BRANCH

E-ISSN: 2980-9231
https://sanad.iau.ir/journal/jce

https://doi.org/...

Vol. x/ No. x/xxx

Research Article

An Optimization Framework based on ADMM Algorithm to Develop P2P Energy Transactions in an Active Distribution Network Using Dynamic Flexibility Envelopes

Mohammad Sedaghat[1] | Esmaeel Rokrok[2*] | Meysam Doostizadeh[3]

[1]Department of Electrical Engineering, Lorestan University, Khorramabad, Iran.
sedaghat.m@fe.lu.ac.ir

[2]Department of Electrical Engineering, Lorestan University, Khorramabad, Iran.
Rokrok.e@lu.ac.ir

[2]Department of Electrical Engineering, Lorestan University, Khorramabad, Iran.
Doostizadeh.m@lu.ac.ir

Correspondence
Esmaeel Rokrok, Professor of Electrical Engineering, Lorestan University, Khorramabad, Iran.
Rokrok.e@lu.ac.ir

Main Subjects:
Energy Management

Paper History:
Received: 28 July 2025
Revised: 5 September 2025
Accepted: 17 September 2025

Abstract

As distributed generation resources continue to grow, there has been a rise in peer-to-peer (p2p) energy trading in local electricity markets connected to distribution networks. A key requirement for effectively implementing p2p energy transactions is to uphold the technical constraints of the network and optimize the capacity of distributed generation resources during these exchanges. Recent research has utilized both static and dynamic operation thresholds that define the acceptable limits for network operations across various time periods. Typically, these thresholds are determined by the distribution system operator (DSO) and conveyed to network participants, often overlooking user preferences in the process. In this paper, a framework called dynamic flexibility envelopes (DFE) is presented, in which the safe threshold of p2p exchanges is determined based on the agreement between energy communities (ECs) and DSO, considering the uncertainty of ECs. The proposed method is implemented in the form of a decentralized optimization problem using the ADMM algorithm on the IEEE standard 69-bus network and using GAMS software. Numerical results show an increase in the volume of real and reactive power transactions compared to other methods. Also, in this paper, the efficiency of the proposed method in implementing the uncertainty of distributed generations is proven by examining different confidence levels.

Keywords: ADMM algorithm, Dynamic Flexibility Envelopes, Energy Community, Peer-to-Peer energy transactions, Active distribution network.

Highlights

- Modeling P2P energy trading in energy communities, including solar and wind generation, fixed and flexible loads, and batteries.
- Increasing the volume of energy transactions by calculating dynamic flexibility envelopes resulting from an agreement between energy communities and the distribution system operator.
- Considering different confidence levels in implementing the uncertainty of distributed generation resources.

Citation: [in Persian].

1. Introduction

The peer-to-peer (P2P) trading framework provides an innovative and cost-efficient approach to energy exchange between producers and consumers, eliminating the need for intermediaries and enhancing efficiency within local electricity markets. This system empowers small-scale producers and consumers to share their surplus energy directly. Beyond its economic advantages, P2P trading enhances network flexibility—an essential goal for distribution system operators (DSOs). Recently, there has been growing interest in developing P2P trading systems to foster environmental sustainability, uphold agent independence within the network, lower electricity costs, support demand-side flexibility services, and improve service quality [1]. P2P trading has notably enhanced local electricity markets and fostered the involvement of prosumers; however, its practical application is accompanied by several challenges. Technical limitations, such as the necessity to uphold acceptable bus voltage levels and to regulate line load capacities, may impede energy transactions within the physical network [2]. Studies, such as [2], suggest that network sensitivity analysis combined with bilateral agreements can help DSOs reject contracts that breach technical limits. However, these centralized methods—coupled with intermediary involvement—raise concerns about user privacy and discourage participation in local electricity markets and P2P exchanges.

Decentralized P2P trading mechanisms, as described in [3, 4], offer prosumers the ability to choose trading partners based on factors like network usage costs, the distance to generators, and power exchange losses. Although these methods incorporate technical constraints and decentralization, they still rely on DSOs to directly manage transactions, which compromises the confidentiality of trade data.

A promising development in modeling technical constraints is the Dynamic Operating Envelope (DOE) approach. This method adjusts energy exchange limits dynamically, taking into account the available capacity of the local network or power system. By calculating and allocating DOEs, DSO can ensure prosumer energy injections remain within permissible voltage ranges [5, 6]. Initially, the DOE concept applied only to exchanges between prosumers and the upstream network. Recent studies, however, have expanded the use of DOE methods for P2P trading. These advancements not only enable prosumers to export energy more efficiently within local electricity markets but also improve their financial returns without breaching network constraints [7–9].

2. Innovation and contributions

An important limitation of existing DOE-based frameworks is the assumption that DOEs are determined solely by the DSO. While this centralization ensures technical compliance, it may limit EC flexibility. To address these issues, this study introduces a framework for calculating feasible transaction regions (FTRs) based on collaborative agreements between DSOs and ECs. This approach incorporates uncertainties and preferences specific to ECs, allowing for more equitable and efficient participation in local electricity markets. It also shifts the DSO's role from enforcer to negotiator, fostering a more dynamic and inclusive energy trading environment. Among the innovations of this paper, the following can be stated:

- By leveraging FTRs, the study ensures that distribution network constraints are continuously updated across time intervals, thereby enabling ECs to make full use of their capacities. Unlike conventional methods, which rely on DOEs calculated by DSOs or impose static constraints, this approach integrates uncertainties and EC preferences into the calculation of exchange regions. This innovation not only preserves technical compliance but also respects participant privacy, maximizing their potential to engage in market activities.
- The inherent uncertainties in energy production and consumption can lead to discrepancies between unilateral DOE calculations performed by DSOs and the priorities of ECs. Such misalignments may result in energy shortages or surpluses relative to pre-established plans, often incurring penalties. The proposed methodology addresses these issues by facilitating the establishment of FTRs through direct negotiations between DSOs and ECs, while considering the specific uncertainties pertinent to each community. This approach redefines the role of the DSO, shifting its function from that of a pricing authority to a collaborative regulator dedicated to reconciling network constraints with the requirements of ECs.
- In this research, peer-to-peer exchanges are conducted with various confidence levels to assess the uncertainty associated with distributed generation resources and are compared with other approaches. This enables an examination of the effectiveness of the proposed method in addressing the uncertainty of distributed generation resources when calculating feasible transaction regions.

3. Materials and Methods

In this paper, a 69-bus IEEE standard system is considered to implement the proposed method. The simulations were performed using the CPLEX calculator in the GAMS software environment using an Intel(R) Xeon(R) E5-1630 v4@3.70 GHz processor and 16 GB of RAM. On this network, five ECs are assumed to exchange energy with each other. Each EC includes distributable (controllable power plant types) and non-distributable (wind and solar turbine) energy production units, adjustable loads, fixed loads, and an energy storage system. The simulation time horizon is also considered to be 24 hours. Also, the optimization problem is solved by using the ADMM method [10].

4. Results and Discussion

In this paper, a standard IEEE 69-bus system [11] is considered to implement the proposed method, as shown in Figure 1. On this network, five ECs are assumed to trade energy with each other. Each EC includes distributable (various types of controllable power plants) and non-distributable (wind and solar turbine) power generation units, adjustable loads, fixed loads, and an energy storage system. The simulation time horizon is also considered to be 24 hours. The ECs are located on buses 22, 32, 46, 49, and 60 of the 69-bus distribution network and exchange energy with each other.

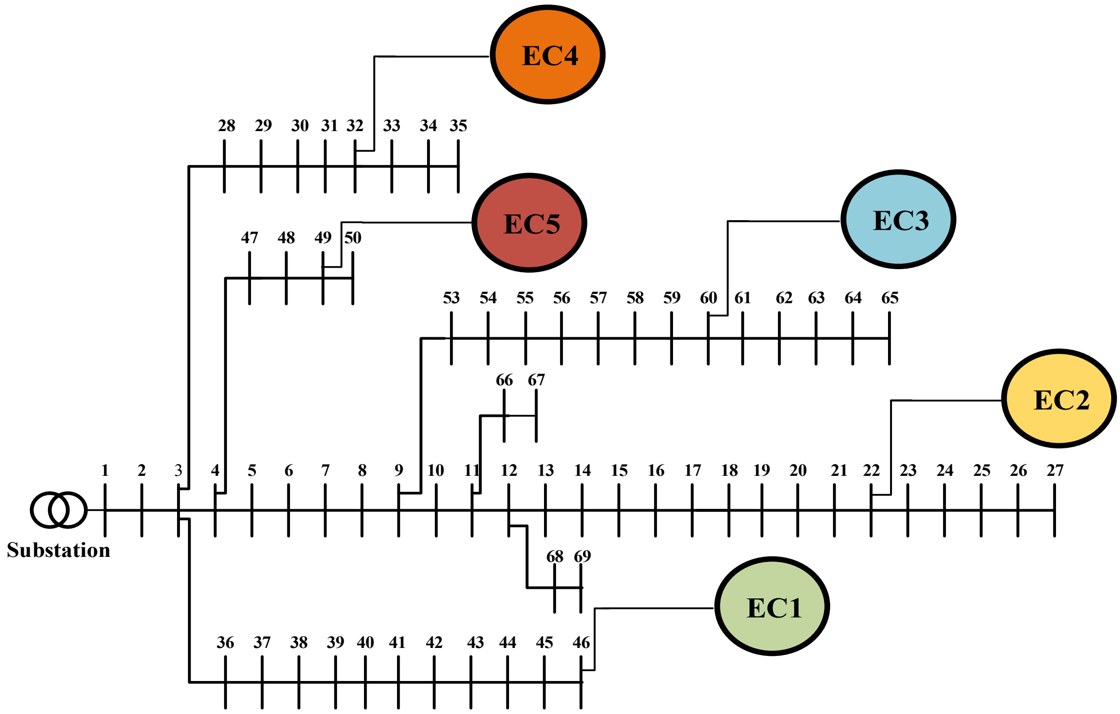

Figure 1. Standard 69 bus network with 5 ECs.

In order to investigate the performance of the proposed method in the real and reactive power loss reduction, the simulation results of the proposed DFE method, the DOE method, and the base case are shown in Table 1. The results show that the peer-to-peer energy exchanges with the proposed method have reduced active losses by 19.75% and reactive losses by 19.7% compared to the base case. In the simulation with the DOE method, active and reactive losses have also been reduced by 13% and 13.6% respectively, compared to the base case. Therefore, the proposed method provides a more appropriate performance in reducing real and reactive losses than the DOE method.

Table 1. Comparison of real and reactive power losses in the proposed method with the base case and DOE-based method

Method	**Active Power Losses (kW)**	**Active Power Losses Reduction (%)**	**Rective Power Losses (kVar)**	**Rective Power Losses Reduction (%)**
Base Case	**2929**	**-**	**1351**	**-**
DOE	**2550**	**13**	**1168**	**13.6**
DFE	**2380**	**19.75**	**1086**	**19.7**

5. Conclusion

In this paper, a peer-to-peer exchange framework between ECs in an active distribution network is presented, in which, in order to increase the volume of energy exchanges in the network and use the maximum capacity of distributed generation resources, the permissible operating limits of the network are maintained by calculating an area called dynamic flexibility envelopes (DFEs). This permissible operating area is calculated from the agreement between the distribution system operator and the energy communities and is not communicated unilaterally by the distribution system operator, as in previous studies. This point causes the ECs to share the operating limits with the distribution system operator, considering their uncertainties, and as a result, the permissible operating area presented in this paper is calculated bilaterally and is welcomed by the ECs. This method has been implemented on a standard 69-bus network and the results show that, in addition to maintaining the technical constraints desired by the distribution system operator during exchanges, the volume of transactions between local producers, which in this paper are ECs, has increased compared to previous methods, which can increase the motivation of ECs to participate in local electricity markets based on peer-to-peer energy trading. In addition, this study, by calculating different confidence levels in determining the uncertainty of ECs, shows the effect of considering the permissible operating threshold in agreement with the system operator in the proposed method compared to other conventional methods.

6. Acknowledgement
The following paper is based on research conducted for the PhD thesis.

References

[1] T. Capper *et al.*, "Peer-to-peer, community self-consumption, and transactive energy: A systematic literature review of local energy market models," *Renewable and Sustainable Energy Reviews,* vol. 162, p. 112403, 2022, doi:10.1016/j.rser.2022.112403.

[2] J. Guerrero, A. C. Chapman, and G. Verbič, "Decentralized P2P energy trading under network constraints in a low-voltage network," *IEEE Transactions on Smart Grid,* vol. 10, no. 5, pp. 5163-5173, 2018, doi: 10.1109/TSG.2018.2878445.

[3] M. Khorasany, A. S. Gazafroudi, R. Razzaghi, T. Morstyn, and M. Shafie-khah, "A framework for participation of prosumers in peer-to-peer energy trading and flexibility markets," *Applied energy,* vol. 314, p. 118907, 2022, doi:10.1016/j.apenergy.2022.118907.

[4] J. Cochran *et al.*, "Flexibility in 21st century power systems," National Renewable Energy Laboratory (NREL), Golden, CO (United States)2014.

[5] Zhou Y, Wang J, Zhang Y, Wei J, Sun W, Wang J. A fully-decentralized transactive energy management under distribution network constraints via Peer-to-Peer energy trading. *IEEE Trans Energy Mark Policy Regulat* 2023;1(4):297–309. http://dx.doi.org/10.1109/TEMPR.2023.3263685.

[6] Liu J, Long Q, Liu R-P, Liu W, Hou Y. Online distributed optimization for spatio-temporally constrained real-time Peer-to-Peer energy trading. *Appl Energy* 2023;331:120216.

[7] Wang, Luhao, Zhuo Wang, Zhengmao Li, Ming Yang, and Xingong Cheng. "Distributed optimization for network-constrained peer-to-peer energy trading among multiple microgrids under uncertainty." *International Journal of Electrical Power & Energy Systems* 149 (2023): 109065.

[8] L. Xu and B. Wang, "Peer-to-peer electricity trading considering voltage-constrained adjustment and loss allocation in blockchain-enabled distribution network," *International Journal of Electrical Power & Energy Systems,* vol. 152, p. 109204, 2023, doi.org/10.1016/j.ijepes.2023.109204.

[9] M. I. Azim, W. Tushar, and T. K. Saha, "Coalition graph game-based P2P energy trading with local voltage management," *IEEE transactions on smart grid,* vol. 12, no. 5, pp. 4389-4402, 2021, doi: 10.1109/TSG.2021.3070160.

[10] A. Aminlou, B. Mohammadi-Ivatloo, K. Zare, R. Razzaghi, and A. Anvari-Moghaddam, "Activating demand side flexibility market in a fully decentralized P2P transactive energy trading framework using ADMM algorithm," *Sustainable Cities and Society,* vol. 100, p. 105021, 2024, doi:10.1016/j.scs.2023.105021.

[11] K. Subbaramaiah and P. Sujatha, "Optimal DG unit placement in distribution networks by multi-objective whale optimization algorithm & its techno-economic analysis," *Electric Power Systems Research,* vol. 214, p. 108869, 2023, doi.org/10.1016/j.epsr.2022.108869.

Declaration of Competing Interest: Authors do not have conflict of interest. The content of the paper is approved by the authors.

Author Contributions: All authors reviewed the manuscript.