Distribution Locational Marginal Prices based on Stochastic Programming and Deep Learning for Managing Energy Market Uncertainty

Hien Thanh Doan, Hongseok Kim*

Sogang Univ.

hiendoanht@sogang.ac.kr, *hongseok@sogang.ac.kr

에너지 시장 불확실성 관리를 위한 확률론적 프로그래밍과 딥러닝 기반 지역적 분산 한계비용

도안탄히앤, 김홍석*
서강대학교

Abstract

The accuracy of energy forecasting is compromised by weather changes, leading to inefficient energy scheduling in the energy market. Furthermore, inaccurate energy predictions impact the reliability and stability of the power system. To address these challenges, we propose an energy market to improve energy management efficiency and reduce the uncertain impact of energy on the power system. This proposed energy market would optimize energy trading strategies for households across various time intervals throughout the day, thereby reducing their energy expenses. Additionally, it would offer improved forecasts of energy demand and generation, averting costly surpluses or deficits. Finally, this initiative would contribute to stabilizing the power grid, fostering greater reliability and efficiency.

I. Introduction

As renewable energy sources (RESs) become more prevalent, energy markets are gradually adopting a more distributed paradigm. To enhance energy resources, communities should consider energy trading among RESs. Energy matching is utilized to maximize participants' profits or minimize their energy costs.

Existing literature explores energy market optimization to minimize energy costs or maximize profits, incorporating strategies such as demand response [1] and considering energy storage systems (ESS) at the household level [2], and optimize the size and location of ESS and consider flexibility in renewable energy planning [3]. However, they often overlook uncertainties in demand or generation, ignore constraints in transmission lines between households, and fail to explicitly define energy exchange costs in distribution energy markets.

To address these gaps, we propose an ESS strategy to mitigate the impact of uncertainty for both community owners (COs) and distribution system operators (DSOs). This strategy incorporates deep learning method and scenario-based method. The integration of both methods is coordinated based on distribution locational marginal pricing (DLMP).

II. Energy Market Problem and Proposed Method

In this study, we considered three main components: the community owner, the distribution system operator, and the main grid.

The CO acts as an aggregator, investigating demands, harnessing resources, and utilizing them to reduce energy costs in the area. Additionally, the CO is responsible for monitoring and managing energy usage, tracking energy consumption, and reporting on it. They also develop strategies to reduce energy consumption, such as promoting energy-efficient appliances.

The DSO primary role is to ensure the smooth and efficient operation of buses in the distribution network by considering the alternating current optimal power flow (AC-OPF) problem. They monitor the reliability and stability of the buses, promptly addressing any issues or disruptions.

To address the uncertainty of energy data in households, we first utilize deep learning-based quantile forecasting to generate scenarios, which serve as inputs in day-ahead scheduling. During the scheduling process, the CO sends energy demand and generation information that households would exchange to the DSO. The DSO optimizes power flow and updates DLMP for transmission lines. Then, the CO uses DLMP to calculate the cost for households to optimize their expenses. The mathematical formulation of the proposed energy market can be found in [4].

It's worth noting that the main grid serves as a compensator for mismatched energy demand and generation in the community, as well as covering power losses in the distribution system. This helps maintain a stable and reliable power supply for consumers.

IV. Performance Evaluation

We simulated the results based on energy data for 50 households in two seasons (summer and winter) using the IEEE 15 bus-system. These results were then compared with the point forecasting method. As depicted in Figure 1, the proposed method yields higher profits than point forecasting. Furthermore, we visually represent the results in AC-OPF of DSO in Figures 2 and 3, indicating that the proposed method mitigates congestion in transmission lines. Finally, we observed that the proposed method improves voltage violations, thereby enhancing the reliability and stability of transmission lines, as shown in Figure 4.

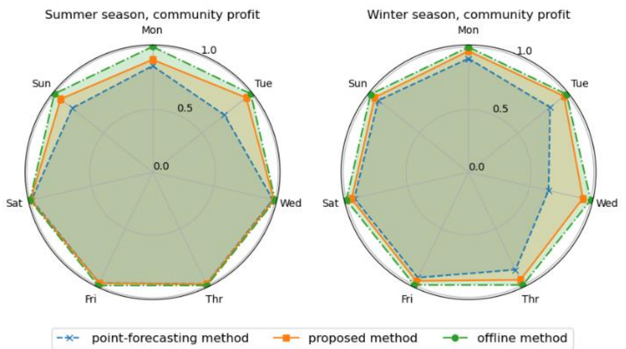

Figure 1. A comparison of profit of three methods [4].

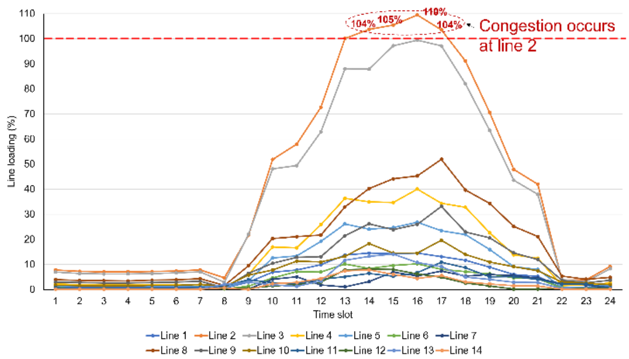

Figure 2. Transmission lines in point forecasting method [4].

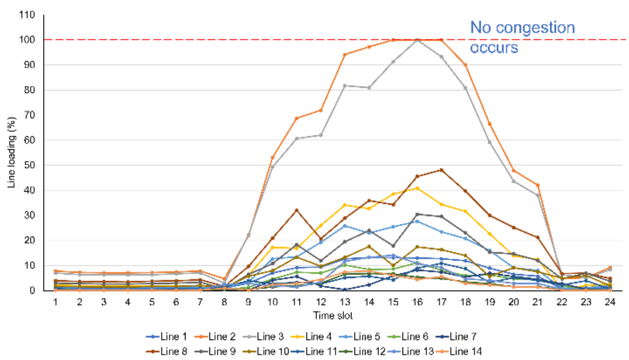

Figure 3. Transmission lines in proposed method [4].

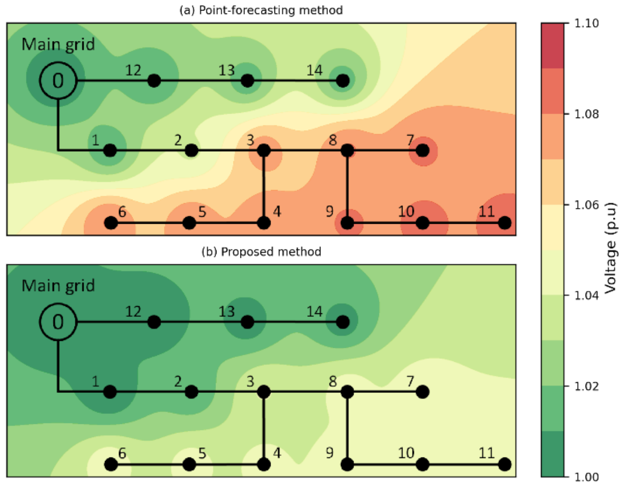

Figure 4. The voltage profile on all buses at time slot 14 [4].

V. Conclusion

By employing a deep learning algorithm to produce quantile scenarios and integrating it with AC-OPF, incorporating DLMP, the proposed method efficiently maximizes households' energy profit compared to existing methods. Additionally, it furnishes highly accurate information to alleviate congestion and voltage variation in transmission lines.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation (NRF), Korea, under project BK21 FOUR (202312001.01) and the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF-2021R1A2C1095435).

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